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THE ESSENTIALS

OF

HISTOLOGY

DESCRIPTIVE AND PRACTICAL

FOR THE USE OF STUDENTS

BY

SIR EDWARD A. SCHÄFER, M.D., SC.D., LL.D., F.R.S.
PROFESSOR OF PHYSIOLOGY IN THE UNIVERSITY OF EDINBURGH
FORMERLY JODRELL PROFESSOR OF PHYSIOLOGY IN UNIVERSITY COLLEGE, LONDON

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PREFACE TO THE TENTH EDITION.

THIS Book is written with the object of supplying the student with directions for the microscopic examination of the tissues. At the same time it is intended to serve as an Elementary Text-book of Histology; comprising the essential facts of the science, but omitting less important details. More complete descriptions will be found in the *Text-book of Microscopic Anatomy*, and in the *Neurology* of *Quain's Anatomy* by the same author.

For conveniently accompanying the work of a class of medical students, the book is divided into fifty lessons. Each of these may be supposed to occupy from one to three hours, according to the relative extent to which the preparations are made beforehand by the teacher, or during the lesson by the students. A few of the preparations cannot well be made in a class, but it has been thought inadvisable to injure the completeness of the work by omitting mention of them.

Only those methods are recommended upon which experience has proved that dependence can be placed, but the directions given are for the most part easily capable of modification in accordance with the ideas or experience of different teachers.

The present edition is somewhat larger than the last. It has been completely revised, and many additional illustrations have been added; most of these are photographs of microscopic preparations.

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THE ESSENTIALS OF HISTOLOGY

INTRODUCTORY

ENUMERATION OF THE TISSUES AND GENERAL STRUCTURE OF ANIMAL CELLS

Animal Histology[1] is the science which treats of the minute structure of the tissues and organs of the animal body; it is studied with the aid of the microscope, and is therefore also termed *Microscopic Anatomy.*

Every part or organ of the body, when separated into minute fragments, or when examined in thin sections, is found to consist of certain textures or tissues, which differ in their arrangement in different organs, but each of which exhibits characteristic structural features.

The following is a list of the principal tissues which compose the body:—

1. **Epithelial.**
2. **Connective**: Areolar, Fibrous, Elastic, Reticular, Lymphoid, Adipose, Cartilage, Bone.
3. **Muscular**: Voluntary, Involuntary, smooth or plain, Cardiac.
4. **Nervous.**

Some organs are formed of several of the above tissues, others contain only one or two.

It is convenient to include such fluids as the *blood* and *lymph* amongst the tissues, because they are studied in the same manner and contain cellular elements similar to those met with in some of the other tissues.

All the tissues are, prior to differentiation, masses of *cells* (embryonic cells). In some tissues elements become developed which take the form of *fibres.* Thus the epithelial tissues are composed throughout life entirely of cells, only slightly modified in structure, and the nervous and muscular tissues are formed of cells which are greatly modified to form the characteristic fibres of those tissues. On the other hand, in the connective tissues an amorphous material becomes formed between the cells which is termed *intercellular substance* or *ground substance,* and in this substance fibres make their appearance, sometimes, as in the fibrous connective tissues, in so large an amount as to occupy the whole of the intercellular substance, and greatly to preponderate over the cells. This ground substance, by virtue of its incorporating a certain amount of inorganic chlorides, has the property of becoming stained brown or black by nitrate of silver and subsequent exposure to light, in which case the cells, which remain unstained, look like white spaces (cell-spaces) in the ground substance. When an epithelial tissue is similarly treated, the narrow interstices between the cells are also stained, from which it is concluded that a similar substance exists in small amount between the cells of this tissue. It has here been termed cement-substance, but it is better to apply to it the general term *intercellular substance.*

---

[1] From ἱστός, a web or texture.

The cells of a tissue are not always separate from one another, but are in many cases connected by bridges of the cell-substance, which pass across the intercellular spaces. This is especially the case with the cells of the higher plants, but it has also been found to occur in animal tissues as in some varieties of epithelium and in cardiac and plain muscular tissue. Occasionally the connexion of the cells of a tissue is even closer, and lines of separation between them are faint or entirely absent. The term *syncytium* is given to any such united mass of cells.

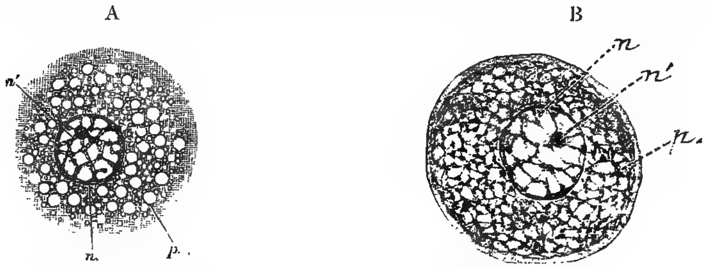

Fig. 1.—Diagrams of cell-structure.

A, diagram of a cell the protoplasm of which appears structureless, but is occupied by vacuoles and granules.

B, diagram of a cell the protoplasm of which appears reticulated.

p, protoplasm, consisting of hyaloplasm and a network of spongioplasm ; *n*, nucleus ; *n'*, nucleolus.

Cells.—A cell is a minute portion of living substance (*cytoplasm*) which is sometimes enclosed by a *cell-membrane* and always contains a specially differentiated part which is known as the *nucleus*.

The **cytoplasm** of a cell (fig. 1, *p*) is composed of *protoplasm*, which consists chemically of proteins or nucleoproteins, with which lipoid substances (such as *lecithin*, a combination of fatty acid with glycerophosphoric acid, and *cholesterol*, a monatomic alcohol) having many of the physical characters of fats, appear always to be associated. The protoplasm tends during life to exhibit movements which are apparently spontaneous, and when the cell is unenclosed by a distinct membrane, a change in the shape, or even in the position of the cell, may be thereby produced. This is characteristically shown in the movements of the unicellular organism known as the amœba (fig. 2); hence the name *amœboid movement*, by which it is generally designated.[1] The protoplasm often, but not always, contains a fine sponge-

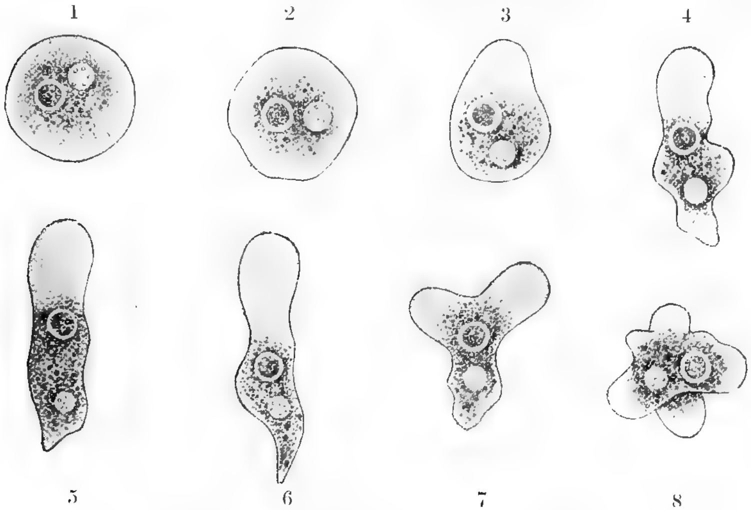

FIG. 2.—SUCCESSIVE CHANGES EXHIBITED BY AN AMŒBA. (Verworn.)

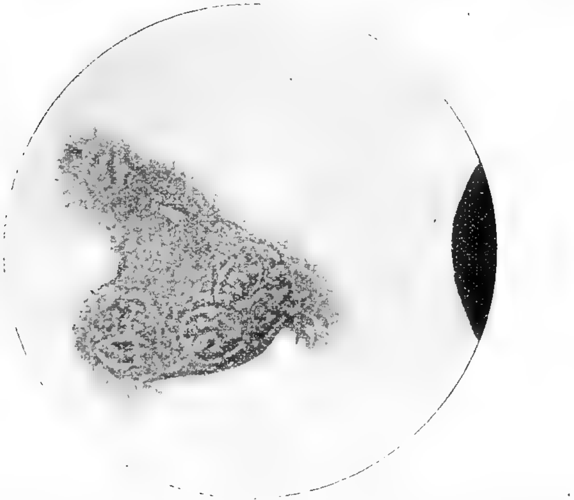

FIG. 3.—UNTOUCHED PHOTOGRAPH OF LIVING LEUCOCYTE OF TRITON, SHOWING RETICULAR APPEARANCE OF THE PROTOPLASM. Magnified 1360 diameters.

The photograph was taken in monochromatic light with Zeiss' 2 mm. apochromatic objective and compensation eye-piece. The polymorph nucleus also exhibits a reticular structure.

---

[1] The amœboid phenomena of cells will be studied later (in the colourless corpuscles of blood).

work, which takes under high powers of the microscope the appearance of a network (see diagram, fig. 1 B, and figs. 3 and 4), the remainder of the

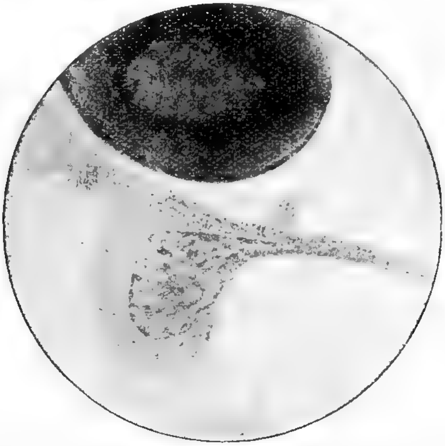

FIG. 4.—A LIVING LEUCOCYTE (WHITE BLOOD CORPUSCLE) OF SALAMANDRA MACULATA, SHOWING LACE-LIKE RETICULAR APPEARANCE OF ITS PROTOPLASM. Magnified 1200 diameters. Untouched photograph.

An erythrocyte (red blood-corpuscle) is included in the photograph. A film of the protoplasm of the leucocyte extends over its margin.

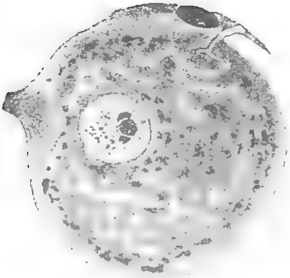

FIG. 5.—TROPHOSPONGIUM (CANALISATION) WITHIN A GANGLION CELL. (E. Holmgren.)

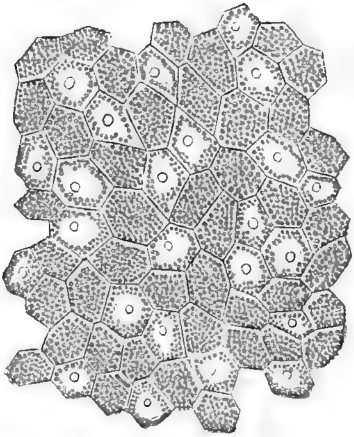

FIG. 6.—EPITHELIUM-CELLS OF SALAMANDER LARVA, STAINED *intra vitam* WITH NEUTRAL RED, SHOWING THE CELL-GRANULES. (Fischel.) Magnified 300 diameters.

protoplasm being a clear substance which occupies the interstices of the spongework, and covers the surface or may project beyond the rest of the cell. A granular appearance is often produced by the knots in the spongework, which, when imperfectly observed, look like separate granules. The material which forms the spongework is termed *spongioplasm*; the clearer material which occupies its meshes is *hyaloplasm*. In other cases cell-protoplasm resembles an emulsion rather than a spongework, being formed of a clear fluid (hyaloplasm), containing globules of a more highly refracting substance suspended in it. These conditions of protoplasm are analogous to the *gel* and *sol* conditions which are characteristic of colloid solutions (see p. 7). The protoplasm of some cells shows a differentiation into fibrils, which may be unconnected or may form a network within the cell. Certain cells exhibit a fine canalisation of their protoplasm (fig. 5); according to Holmgren the canaliculi are occupied by branching processes of other (nutrient) cells, which form what he has termed a "trophospongium."

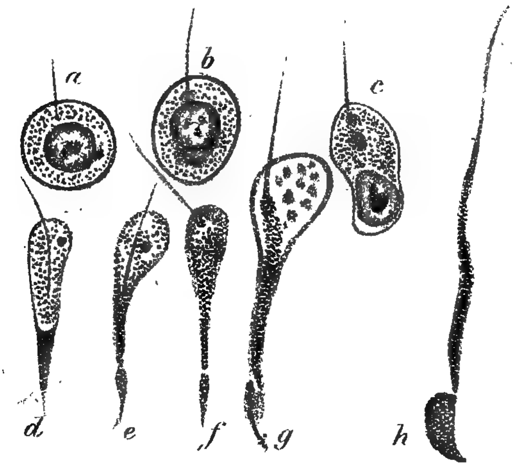

FIG. 7.—CELLS FROM THE TESTICLE OF THE MOUSE IN PROCESS OF TRANSFORMATION INTO SPERMATOZOA. (Benda.)

The "mitochondria" are darkly stained and are seen in the successive stages (*a* to *g*) to be arranging themselves so as to constitute the spiral filament of the spermatozoon (*h*).

Besides the colloid globules above-mentioned, which can only be seen with the ultramicroscope, protoplasm often includes actual granules of a protein nature (fig. 6). The granules are of several kinds. Those contained in some cells stain only with alkaline dyes (*basiphil*), those in others only with acid dyes (*oxyphil*), whilst some cells contain granules staining with both basic and acid dyes (*amphophil*), and others, granules staining only with neutral dyes (*neutrophil*). Certain of these granules have been regarded as essential constituents of the protoplasm (Altmann), being closely associated with what is, chemically, the most active part of the cell, the part, namely, in the neighbourhood of the nucleus; indeed they appear to become formed in this part (if not actually from the nucleus) and from it to extend throughout the cell. When fibrils are formed in the protoplasm, they are produced from the granules in question, to which the name *mitochondria* was given by Benda (fig. 7). The mitochondria are sometimes collected near the nucleus into a spherical mass which stains more deeply than the rest of the cytoplasm (fig. 8). To this body the term *paranucleus* has been applied. In many cells other materials are included in the cytoplasm which are not factors in its constitution, such as pigment granules, fat globules, and vacuoles containing watery fluid, with or without glycogen or other substances in solution. Materials which are thus included in the protoplasm of a cell are either stored up for the nutrition of the cell itself, or are converted into substances which are eventually extruded from the cell in order to serve some purpose useful to the whole organism, or to be got rid of from the body. The term *paraplasm* is employed to denote any such materials within a cell. Paraplasm is often present in sufficient quantity to reduce the cytoplasm to a relatively small amount, the bulk of the cell being occupied by other material, as when starch becomes collected within vegetable cells or fat within the cells of adipose tissue. It is frequently the case that the paraplasm is confined mainly to the middle of the cell in the neighbourhood of the nucleus, an external zone of the protoplasm being left clear. The two portions of protoplasm which are thus imperfectly differentiated from one another are termed respectively the *endoplasm* and the *exoplasm*. They are exhibited in the amœba (fig. 2), and in the white blood-corpuscle (fig. 9).

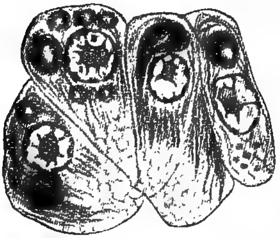

FIG. 8.—PANCREAS CELLS OF FROG, SHOWING PARANUCLEUS AND CHONDROMITOME FIBRILS FORMED FROM MITOCHONDRIA. (Matthews.)

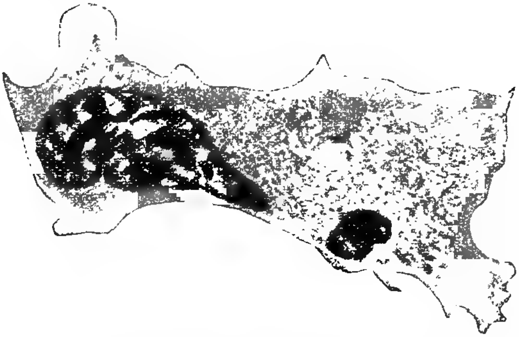

FIG. 9.—PHOTOGRAPH OF LEUCOCYTE OF TRITON, FIXED WHILST IN AMŒBOID CONDITION BY JET OF STEAM DIRECTED ON TO COVER-GLASS, AND SUBSEQUENTLY STAINED WITH HÆMATOXYLIN. Magnified 1360 diameters. Untouched photograph.

The protoplasm shows an internal granular and reticular endoplasm and a clear exoplasm.

According to the view advocated by Bütschli the apparent reticulum or spongioplasm of a cell is the optical effect of a soft honeycomb or froth-like structure; in other words, the meshes of the reticulum do not communicate with one another as in a sponge, but are closed cavities as in a honeycomb. Bütschli finds indications of the same alveolar structure in all cells, including nerve-fibres and muscle-fibres, and has devised experiments with drops of froth made up of a mixture of oil and alkaline carbonate or sugar solution, which, when examined in water under the microscope, imitate very closely not only the structural appearance (fig. 10) but even the so-called spontaneous or amœboid movements of actual protoplasm. It may be stated, however, that although it is a matter of difficulty to determine whether a microscopic reticulum is a spongework or a honeycomb, it is probable that neither structure is essential to living substance, for the outermost layer of the cell-protoplasm, which is usually the most active in exhibiting movements, often shows no indication of any structure. And further, it has been shown by Hardy that a colloid solution such as that which exists in protoplasm may, under some circumstances, appear homogeneous and under others may separate out into two parts, one more solid the other more fluid, and after such separation may exhibit either a granular, a reticular, or a honeycomb structure, according to circumstances (*gel* and *sol* conditions of Graham). Nor is a "froth" necessary for the imitation of amœboid movements, for similar movements, due to changes in surface tension, are exhibited by a simple oil drop or a drop of oil-clad albumen when brought in contact with solution of soap or of an alkali (Berthold, Quincke). Indeed, drops of any fluid are subject to changes of surface tension when exposed to varying external influences, and such changes are invariably accompanied by alterations in form of the drop. It follows from such observations that the amœboid movement of cells which used to be regarded as especially significant of the presence of life, is capable of being explained by well-known physical laws, and it is, therefore, superfluous to assume the possession of a special form of energy ("vital force") to explain the occurrence of this phenomenon.

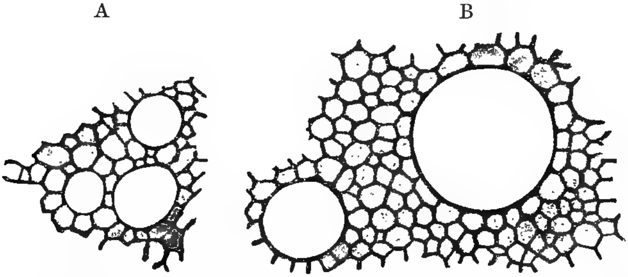

FIG. 10.—COMPARISON OF PROTOPLASM WITH OIL AND WATER EMULSION. (Verworn, after Bütschli.)

A, protoplasm of Thalassicola.
B, froth-like appearance of a mixture of oil and cane sugar.

There are grounds for believing that a very fine pellicle covers the exterior of the protoplasm of all free cells, and that this pellicle is composed of a material which, although not soluble in water, is permeable to watery fluids, and may also allow the passage of solids without rupture. Such a material might be furnished by the lipoids (Overton), which are, as we have seen, constant constituents of cell-protoplasm. It must, however, be stated that, although probable, it has not been proved that these substances are especially collected at the surface of protoplasm. It must further be borne in mind that either a sponge-like or honeycomb structure would have the effect of producing a large number of "internal surfaces" within protoplasm, at all of which changes of surface tension and adsorption are liable to occur.[1] The essentially fluid nature of cytoplasm during life is proved by the dancing (Brownian) movement of its granules; this movement, which is of a physical nature, only occurs in fluids.

Properties of living matter.—Living cells exhibit (1) *irritability* or the property of responding to stimuli; (2) *metabolic or chemical changes* which result in *assimilation* or the taking in of nutrient matter and converting it into living substance (anabolism), and *disassimilation*, the property of breaking down such substance (katabolism); (3) *reproduction* resulting in the multiplication of individuals. Of these properties (2) and (3) are governed by the nucleus, and (3) is usually initiated by the centrosome (see below). The irritability of the cell depends, however, mainly upon the cytoplasm. It is in consequence of this property that protoplasm reacts, sometimes by contraction, sometimes by relaxation, to mechanical, chemical, thermal, and electrical stimuli, and in the case of some cells (*e.g.* the pigment-cells and cones of the retina) to the stimulus of light. The amœboid movements of cells are also a manifestation of irritability, being produced and influenced by various external conditions and stimuli. Sometimes the result of a stimulus is to cause a cell or organism to move towards the source of excitation (attraction); in other cases the movement is in the reverse direction (repulsion). The terms positive and negative chemotaxis, phototaxis, thermotaxis, thigmotaxis and the like, are used to indicate the nature of the effects produced by various forms of stimulation.

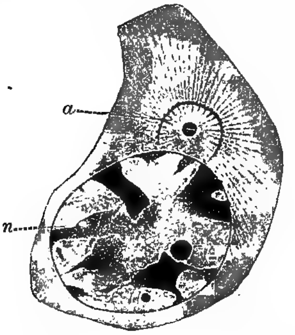

FIG. 11.—A CELL (WHITE BLOOD-CORPUSCLE) SHOWING ITS ATTRACTION-SPHERE. (M. Heidenhain.)

In this, as in most cases, the attraction-sphere, *a*, lies near the nucleus, *n*.

Attraction-sphere and centrosome. — In some cells, as already indicated, there are fine but distinct striæ or fibrils (*cytomitome*) running in definite directions. These are very commonly met with in fixed cells, such as various kinds of epithelium-cells, nerve-cells, and muscle-cells. But besides these permanent differentiations, which appear to be related to special functions, there are other fibril-like structures in the cell-protoplasm, associated with what is known as the *centrosome* (fig. 11). This consists of a minute particle (*attraction-particle, centriole*), usually situated near the nucleus, and staining darkly with iron-hæmatoxylin, surrounded by a clear area (*attraction-sphere*), and from it radiate into the surrounding protoplasm a number of fine varicose lines or threads. The attraction-sphere, with its central particle, was first noticed in the ovum and was supposed to be peculiar to the egg cell, but it has now been recognised in very many kinds of cells, and is of nearly universal occurrence in animal cells. The centrosome is frequently double, the twin-spheres being connected by a spindle-shaped system of delicate fibrils (*achromatic spindle*): this duplication invariably precedes the division of a cell into two.

In some cells the centrioles are multiple; this is frequently the case with leucocytes and always with the giant-cells of bone-marrow (fig. 13). The material which immediately surrounds the centrosome, and of which the radiating fibres and the fibres of the spindle are composed, is considered by some to be distinct in nature from the general protoplasm : it has been termed *archoplasm*. The centrosome and archoplasm may have an existence independent of one another ; *e.g.* no centrosome has been found in the cells of the higher plants, although the archoplasmic fibres are very well marked in them during cell-division.

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[1] For a discussion of the physical phenomena associated with such structure, the student is referred to the *Principles of General Physiology*, by Professor W. M. Bayliss.

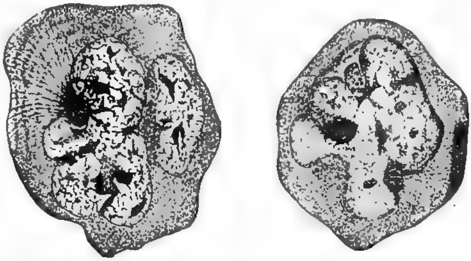

Fig. 12.—Cells with irregular lobed nuclei from bone-marrow of rabbit. (M. Heidenhain.)

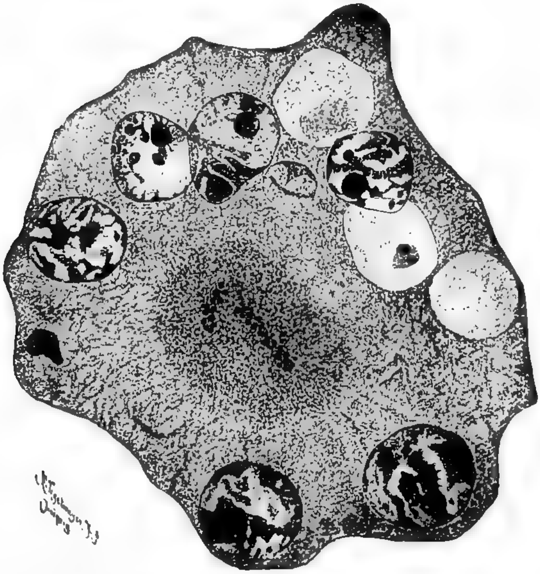

Fig. 13.—Multi-nucleated giant-cell from lymph gland of rabbit. (M. Heidenhain.)

A **cell-membrane** is rarely distinct in animal cells. When present, it is usually formed by transformation of the external layer of the protoplasm ; its chemical nature has not been sufficiently investigated. In plant-cells a membrane formed of cellulose is of common occurrence.

The **nucleus** of the cell is a spherical, ovoid, elongated, annular, or irregularly lobulated vesicle (figs. 1, 3, 5, 9, 11, 12), embedded in the protoplasm. Cells often have two nuclei, and occasionally several (fig. 13). The nucleus is bounded by a so-called *membrane* which encloses a clear substance (*nuclear hyaloplasm, karyoplasm*) (fig. 14); the whole of this substance is generally pervaded by an irregular network of fibres, some coarser, others finer (*nuclear reticulum, karyomitome*) (figs. 14, 15). The membrane is formed by karyomitome, of which it constitutes the outermost layer. The knots of the nuclear reticulum are sometimes very distinct, and they then give an appearance of conspicuous granules within the nucleus (*pseudonucleoli*), which are not to be confounded with the highly refracting spherical particle known as the **nucleolus**, which is almost always present as a distinct structure. Sometimes two true nucleoli are found (fig. 14). Occasionally the nucleolus has a vacuole-like globule in its interior. The material of the nucleolus, although basiphil, differs in its chemical and staining reactions from the nuclear reticulum. During cell-division it disappears. Whether it blends with the karyomitome fibres or becomes absorbed and removed is uncertain. The nucleoli may sometimes be seen to be bodily extruded from the nucleus into the protoplasm. The nuclear membrane and intranuclear fibres stain deeply with hæmatoxylin and with basic dyes generally; this property distinguishes them from the nuclear matrix, and they are accordingly spoken of as *basi-chromatic*—containing *basichromatin*, which in the nucleus appears to be chemically identical with *nuclein* (or rather with the constituent of nuclein known as nucleic acid). On the other hand the nuclear hyaloplasm is usually *oxychromatic*. These staining properties depend upon the presence of minute basiphil or oxyphil granules. The basiphil granules are united, by a non-staining material termed *linin*, into the threads or fibres which compose the network.

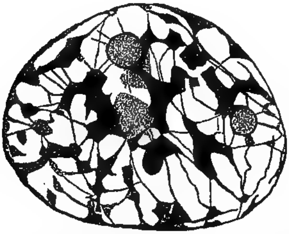

FIG. 14.—NUCLEUS OF AN EPITHELIAL CELL OF SALAMANDER LARVA. (M. Heidenhain.) Magnified 2300 diameters.

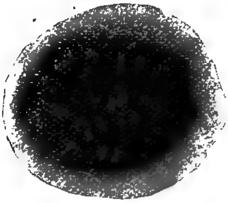

FIG. 15.—LYMPHOCYTE OF TRITON, SHOWING THE RETICULAR STRUCTURE OF ITS NUCLEUS. Magnified 2000 diameters. Untouched photograph.

The cell was fixed by steam, and afterwards stained with hæmatoxylin.

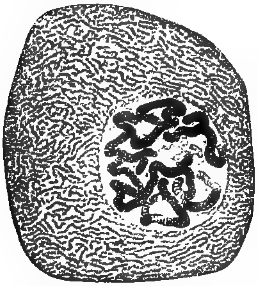

FIG. 16.—GLAND-CELL OF CHIRONOMUS. (Flemming.)

Sometimes instead of being connected to form a network the intranuclear fibres take the form of convoluted filaments (*chromosomes*), having a skein-like arrangement (fig. 16). This condition is always found when a nucleus is about to divide, but it may also occur in the resting state. These filaments may sometimes be seen with high magnification to be made up of fine juxtaposed particles (*chromomeres*) arranged either in single or double rows (figs. 17, 18). The nuclear fibres are sometimes clumped together into a solid mass which comprehends the nucleolus when this is present, and has the appearance of an enlarged nucleolus. The fibres within the nucleus have been observed to undergo spontaneous changes of form and arrangement, but these become much more evident during cell division. The division of the protoplasm is always preceded by that of the nucleus, and the nuclear fibres undergo a series of remarkable transformations which are known collectively by the term *karyokinesis* (Schleicher) or *mitosis* (Flemming). These changes may easily be studied in the division of epithelium cells, but exactly similar phenomena have been shown to occur in cells belonging to other tissues.

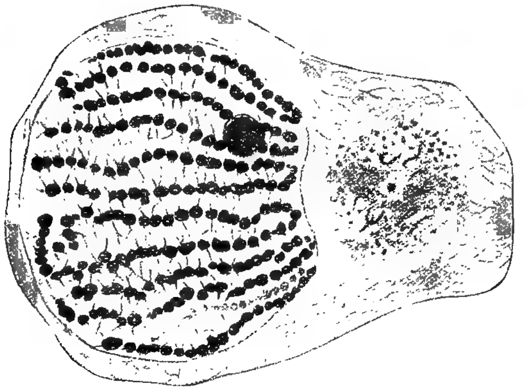

FIG. 17.—SPERMATOCYTE OF PROTEUS, SHOWING CHROMOSOMES OF NUCLEUS FORMED OF PARTICLES OF CHROMATIN UNITED BY ACHROMATIC FILAMENTS. (F. Hermann.)

The nucleolus is distinct from the chromosomes. In the cytoplasm an archoplasmic mass containing mitochondria is seen on the right.

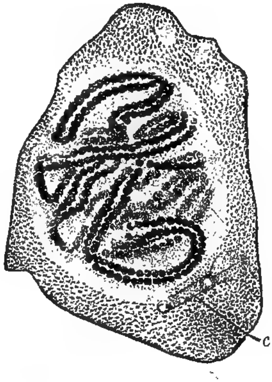

FIG. 18. — CELL SHOWING CHROMOSOMES OF NUCLEUS IN THE FORM OF THREADS COMPOSED OF DOUBLE ROWS OF CHROMOMERES. (F. Hermann.)

c, centrosome with uniting spindle.

The simple division of a nucleus by a process of fission without karyokinetic changes is termed *amitotic division* (figs. 19, 20); it occurs in comparatively rare instances, and is often not followed by the division of the cell, so that it is apt to result in the formation of bi-nucleated and multi-nucleated cells, as in the superficial layer of the epithelium of the urinary bladder and in some of the giant cells of bone-marrow.

The nucleus of the cell is not only concerned with its division and multiplication in the manner to be described, but takes an active part in the chemical (metabolic) processes which occur in the protoplasm. Hence cells deprived artificially of their nuclei do not assimilate nourishment, and lose any power of secretion they may have possessed, although the protoplasm may continue for a time to live and exhibit amœboid movements.

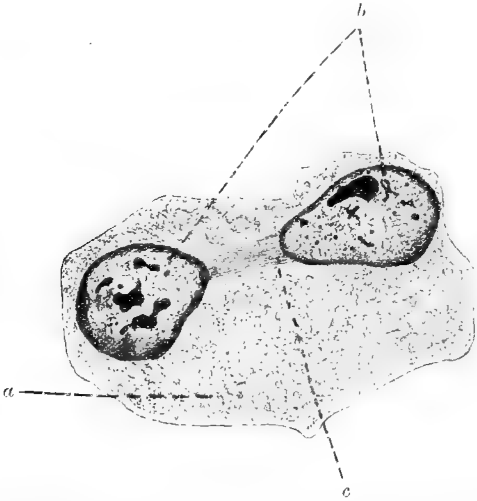

FIG. 19.—CELL OF BLADDER EPITHELIUM, SHOWING AMITOTIC DIVISION OF NUCLEUS. (Nemileff.)

a, cytoplasm; *b*, daughter nuclei; *c*, strand of fibrils uniting daughter nuclei.

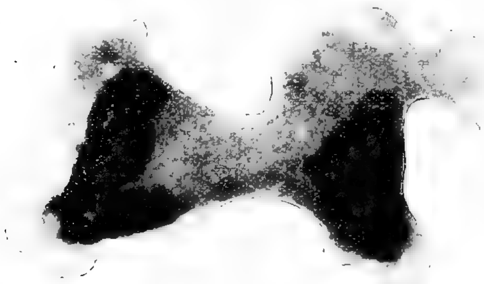

FIG. 20.—A LEUCOCYTE OF TRITON APPARENTLY UNDERGOING AMITOTIC DIVISION OF ITS NUCLEUS. Magnified 1360 diameters. Untouched photograph.

The nucleus is separated into two nearly equal parts, and the protoplasm is collecting around them and becoming constricted in the intermediate part of the corpuscle. The corpuscle was fixed by a jet of steam and stained with hæmatoxylin.

Division of cells.—The division of a cell is preceded by the division of its attraction-sphere, and this again appears to determine the division of the nucleus. The latter, in dividing, passes through a series of remarkable changes, which may be briefly summarised as they occur in typical animal cells such as the epithelium-cells of Salamandra, as follows:—

1. The network of chromoplasm-filaments of the resting nucleus becomes transformed into a sort of *skein*, formed apparently of one long convoluted filament, but in reality consisting of a number of filaments (*spirem*); the nuclear membrane and the nucleoli disappear or are merged into the skein (fig. 21, *a* to *d*).

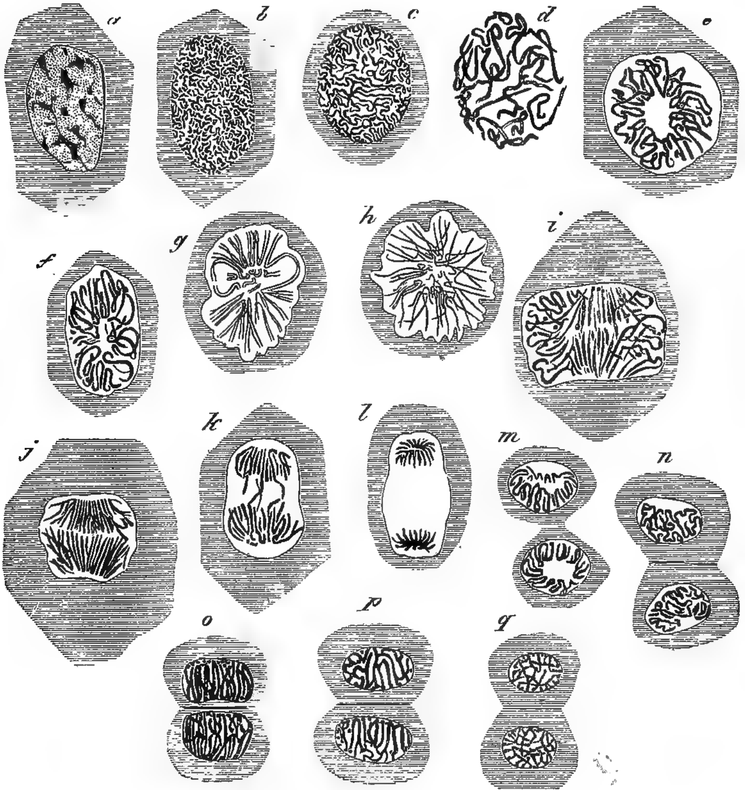

Fig. 21.—Epithelium-cells of salamander larva in different phases of division by karyokinesis or mitosis. (Flemming.)

2. The filament breaks into a number of separate portions, often V-shaped, the *chromosomes*. The number of chromosomes varies with the species of animal or plant; in some animals the dividing nuclei may contain at this stage only four chromosomes; in man there are generally said to be twenty-four in the ordinary or somatic cells, although Winiwarter gives

double that number; other plants and animals have even more than this. As soon as the chromosomes become distinct they are arranged radially around the equator of the nucleus like a star (*aster*, fig. 21, *e*, *f*, *g*).

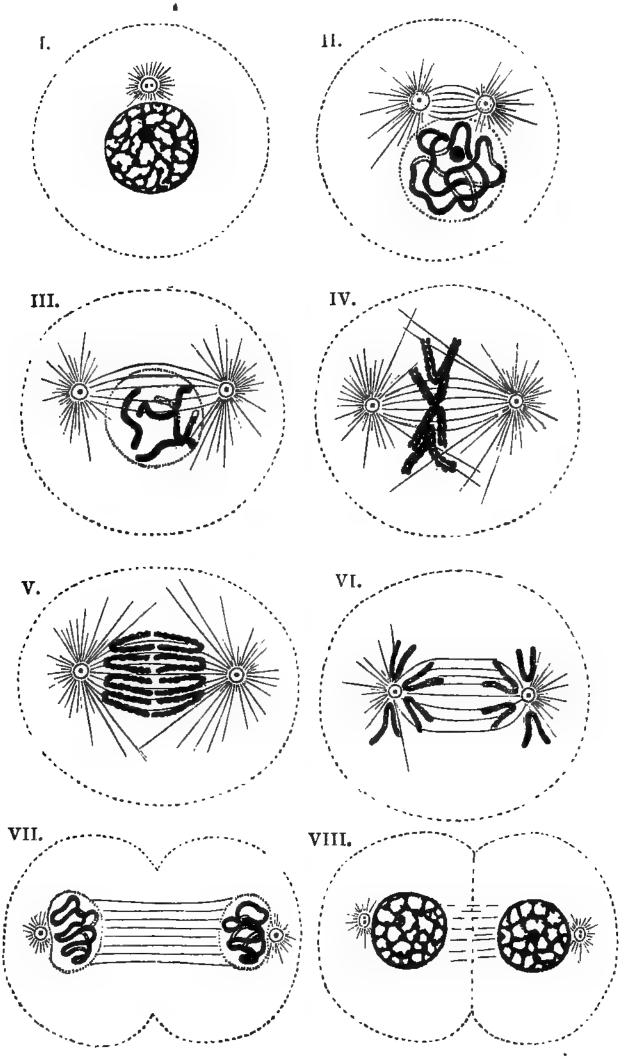

FIG. 22.—DIAGRAM SHOWING THE CHANGES WHICH OCCUR IN THE CENTROSOMES AND NUCLEUS OF A CELL IN THE PROCESS OF MITOTIC DIVISION.

The nucleus is supposed to have four chromosomes.

3. Each of the chromosomes splits longitudinally into two, so that they are now twice as numerous as before (*stage of cleavage*, fig. 21, *h*, *i*). This longitudinal cleavage may occur at an earlier stage.

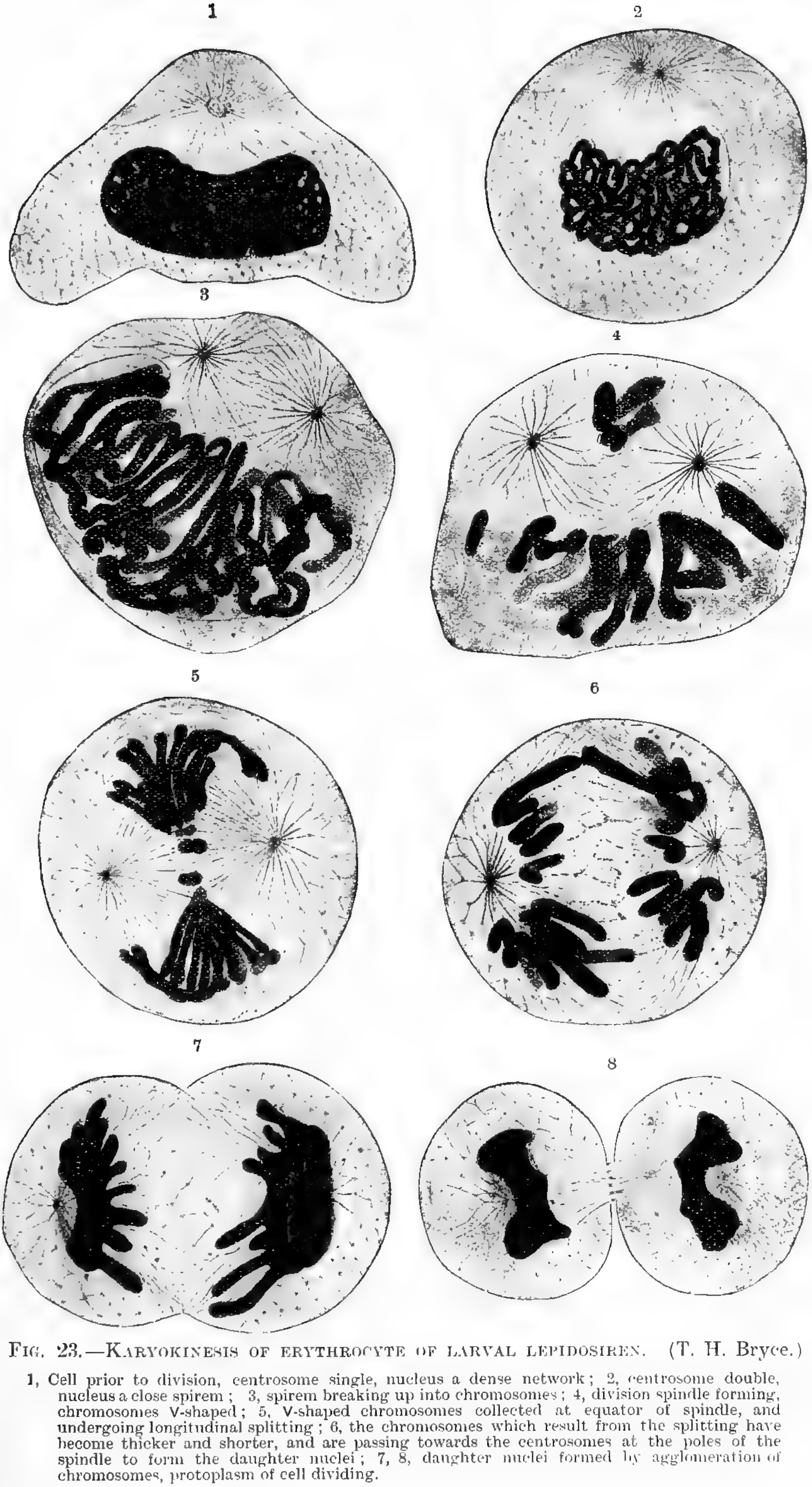

FIG. 23.—KARYOKINESIS OF ERYTHROCYTE OF LARVAL LEPIDOSIREN. (T. H. Bryce.)

1, Cell prior to division, centrosome single, nucleus a dense network; 2, centrosome double, nucleus a close spirem; 3, spirem breaking up into chromosomes; 4, division spindle forming, chromosomes V-shaped; 5, V-shaped chromosomes collected at equator of spindle, and undergoing longitudinal splitting; 6, the chromosomes which result from the splitting have become thicker and shorter, and are passing towards the centrosomes at the poles of the spindle to form the daughter nuclei; 7, 8, daughter nuclei formed by agglomeration of chromosomes, protoplasm of cell dividing.

4. The fibres separate into two groups, the ends being for a time interlocked (fig. 21, *j, k*).

5. The two groups pass to the opposite poles of the now elongated nucleus and form a star-shaped figure at either pole (*diaster*, fig. 21, *l*). Each of the stars represents a daughter nucleus.

6, 7, 8. Each star of the diaster goes through the same changes as the original nucleus, but in the reverse order—viz., a skein, at first more open and rosette-like (fig. 21, *m*), then a closer skein (fig. 21, *n*), then a network (fig. 21, *o, p, q*); passing finally into the typical reticular condition of a resting nucleus (see also figs. 22, 23).

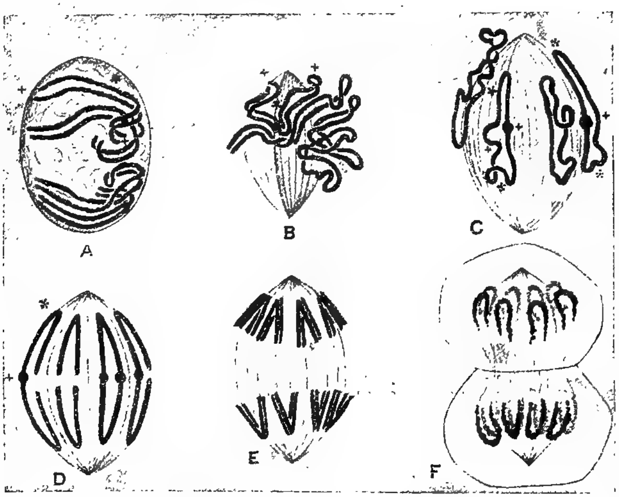

FIG. 24.—DIAGRAM OF THE CHANGES SHOWN IN HETEROTYPICAL MITOSIS, EIGHT CHROMOSOMES ONLY BEING REPRESENTED.

In *A* and *B* they are arranged in pairs; in *C* they are united to four loops, which are separating in *D*. In *E* a longitudinal splitting of each chromosome is occurring. *F*, daughter nuclei each with eight chromosomes.

The splitting and separation of the chromosomes is often spoken of as the *metaphase* (*metakinesis*); the stages leading up to this being termed the *anaphase*, and those which lead away from it the *kataphase*, the final stage being spoken of as the *telophase*.

The mode of division of the nuclear chromatin above described is known as *somatic* or *ordinary mitosis*, to distinguish it from two modes of division which are only seen normally at certain stages of multiplication of the generative cells (gonads), and which are known as *heterotypical* and *homotypical mitosis* (figs. 24, 25). In the latter the chromosomes do not undergo the usual longitudinal splitting, but one half of the total number passes into each daughter nucleus, so that the number of chromosomes in each of these is only one half the usual somatic number. This is termed the *reduction-division*. Heterotypical mitosis (which immediately precedes the homotypical) is characterised by a peculiar arrangement of the chromosomes, which, before separating to pass to the daughter nuclei, tend to adhere together in the form of loops or rings, or in the case of short straight chromosomes into small quadrangular masses (tetrads) (see figs. 26, 27).

It is further noteworthy that the generative cells which undergo the reduction-division above described exhibit either immediately (sperm-cells) or a long while

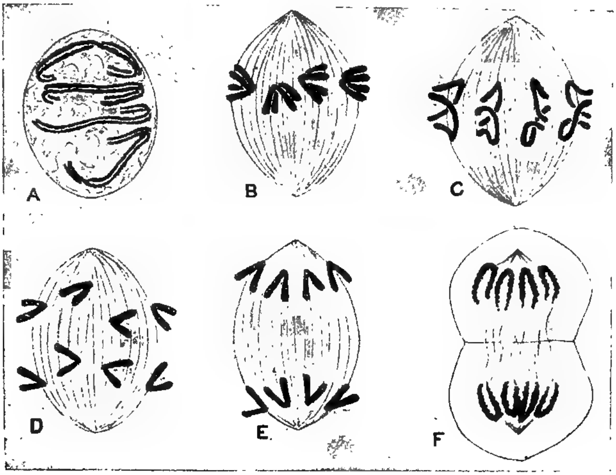

FIG. 25.—DIAGRAM OF THE CHANGES OCCURRING IN HOMOTYPICAL MITOSIS.

In *A* and *B* the eight chromosomes are united into pairs: in *C*, *D*, and *E* they are shown separating from one another, without any longitudinal cleavage. *F*, daughter nuclei each with only four chromosomes.

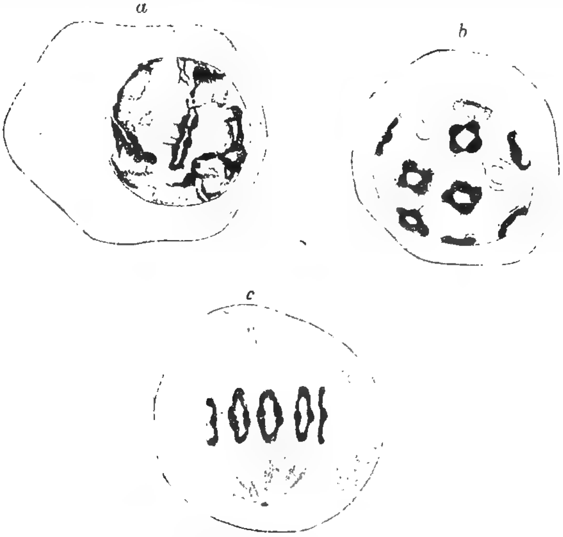

FIG. 26.—THREE STAGES OF HETEROTYPICAL MITOSIS IN SPERMATOCYTE OF TRITON. (Moore.)

a, geminal condition of chromosomes; *b*, gemini arranged in quadrate loops or tetrads; *c*, separation of tetrads into the duplex chromosomes of the daughter nuclei.

(germ-cells) before the final divisions a remarkable series of changes in their nuclear chromatin; the chromosomes first becoming distinct in place of forming a network, then entangled together at one side of the nucleus (synaptic condition), and finally again becoming distinct, but now arranged in pairs (gemini) which later take various forms, such as double rods, loops, or rings as in heterotypical mitosis, but without necessarily forthwith proceeding to nuclear division.

The protoplasm of the cell divides soon after the formation of the diaster (fig. 21, *m*). During division fine lines are seen in the protoplasm radiating from the centrosomes at the poles of the nucleus, whilst other lines form a spindle of *achromatic fibres* within the nucleus, diverging from the poles towards the equator (figs. 22 to 25). These are usually less easily seen than the basichromatic fibres or chromosomes, but are not less important, for they are derived from the attraction-spheres. The latter, with their centrosomes, as we have seen, always initiate the division of the cell; indeed they are often found divided in the apparently resting nucleus, the two particles being united by a small system of fibres forming a minute spindle at one side of the nucleus. When mitosis is about to take place this spindle enlarges, and as the changes in the chromatin of the nucleus which have been above described occur—which changes involve the disappearance of the nuclear membrane—the spindle gradually passes into the middle of the mitotic nucleus, with the two poles of the spindle at the poles of the nucleus, and with the fibres of the spindle therefore completely traversing the nucleus (figs. 22, 23). The spindle fibres appear to form directing lines, along which the chromosomes pass, after the cleavage, towards the nuclear poles to form the daughter nuclei.

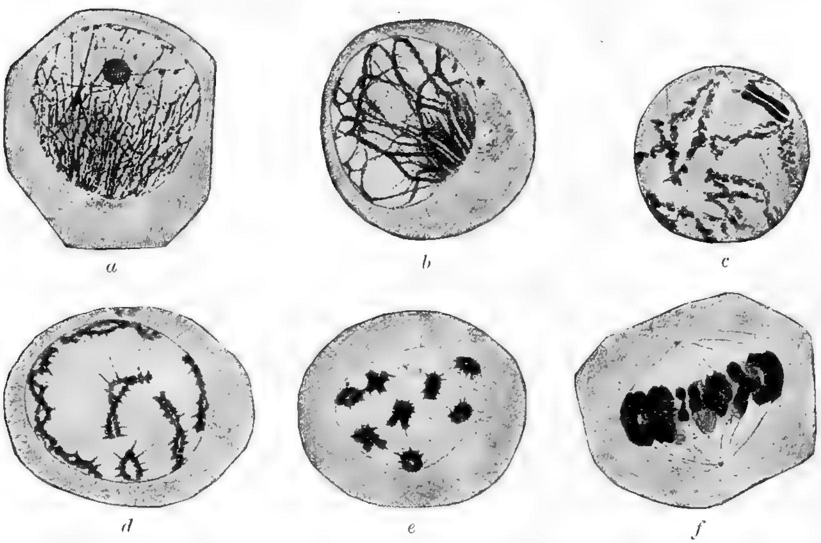

FIG. 27.—SPERMATOCYTES OF MYXINE SHOWING SYNAPTIC CONDITION IN *a* AND *b*, GEMINAL CONDITION IN *c* AND *d*, AND FORMATION OF TETRADS AND CHROMOSOME RINGS IN *e* AND *f*. (Schreiner.)

In some cells, especially in plants, the line of division of the protoplasm of the cell becomes marked out by thickenings upon the fibres of the spindle which occur just in the plane of subsequent division, and have been termed collectively the *cell-plate* (fig. 29). But in most animal cells no cell-plate is formed, the protoplasm simply becoming constricted into two parts midway between the two daughter nuclei. Each daughter cell so formed retains one of the two attraction-particles of the spindle as its centrosome,

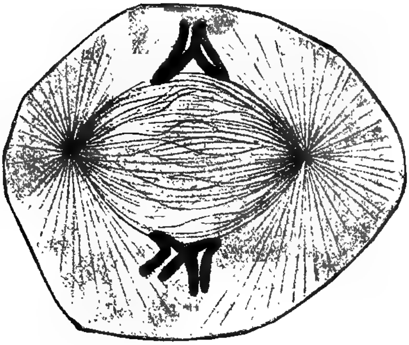

FIG. 28.—SPERMATOCYTE OF SALAMANDRA SHOWING ACHROMATIC FIBRES OF SPINDLE AND OTHERS RADIATING FROM CENTROSOMES. (Flemming.)

Four chromosomes are represented at the equator of the spindle.

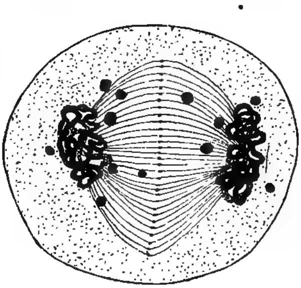

FIG. 29.—CELL-PLATE IN DIVIDING SPORE-CELL OF LILY.

(Gurwitsch, after Zimmermann.)

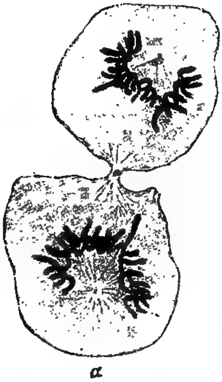

FIG. 30.—DIVIDING CELL CONSTRICTED TO FORM TWO DAUGHTER CELLS EACH WITH CENTROSOME. (Geberg.)

The particle at the junction of the daughter cells represents a rudimentary cell-plate.

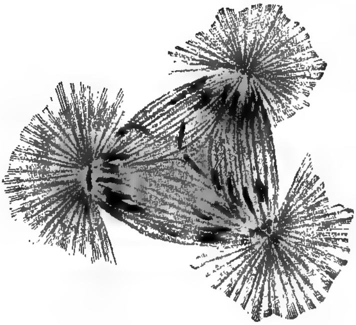

FIG. 31.—TRIPOLAR MITOSIS IN ECHINODERM OVUM. (E. B. Wilson.)

and, when the daughter cells are in their turn again about to divide, this centrosome divides first and forms a new spindle, and the whole process goes on as before. Rarely the division of a nucleus is into three or more parts instead of two (fig. 31). In such cases the centrosome becomes correspondingly multiplied and the achromatic system of fibres takes a more complex form than the simple spindle.

It has been shown by Leduc that the appearance of the division spindle and the changes which the chromosomes undergo can be roughly imitated by allowing solutions of an electrolyte of different concentration, one of which contains carbon particles in suspension, to mix gradually (fig. 32). Indeed that electrical attraction and repulsion come into play in the process of karyokinesis is more than probable (R. S. Lillie). W. B. Hardy finds evidence in the resting cell also of the existence of opposite electric charges in the proteins of the cytoplasm (+) and those of the nucleus (–).

Division of the ovum.—Usually the two daughter cells are of equal size; but there is a notable exception in the case of the ovum, which, prior to fertilisation, divides twice (by hetero- and homo-typical mitosis respectively) into two very unequal parts, the larger of which retains the designation of ovum, while the two small parts which become detached from it are known as the *polar bodies* (fig. 29). In the formation of the second polar body a *reduction-division* occurs, and the nucleus of the ovum, after the polar bodies are extruded, contains only one half the number of chromosomes that it had previously: *e.g.* twelve in place of the normal twenty-four in man (see p. 13), and two instead of four in *Ascaris megalocephala* (var. bivalens), (fig. 33 *C*). Should fertilisation supervene the chromosomes which are lacking are supplied by the male element (sperm-cell), the nucleus of which has also undergone, in the final cell-division by which it was produced, the process of reduction in the number of chromosomes to one half of the normal number. The two reduced nuclei —which are formed respectively from the remainder of the nucleus of the oocyte (ovum) after extrusion of the polar bodies, and from the head of the spermatozoon, which contains the nucleus of the sperm-cell—are known

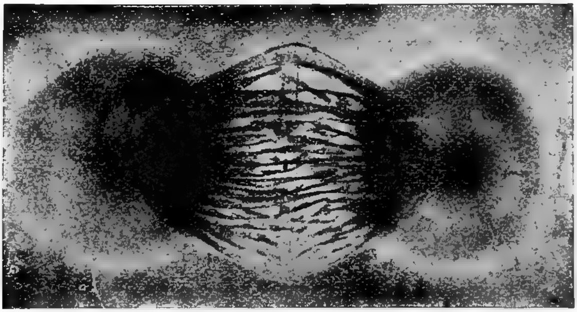

FIG. 32.—IMITATION OF DIVISION SPINDLE PRODUCED DURING THE MIXING OF DROPS OF A LESS CONCENTRATED SOLUTION OF SODIUM CHLORIDE CONTAINING PARTICLES OF CHINA INK IN SUSPENSION WITH A SOLUTION OF THE SAME SALT OF GREATER DENSITY. (Verworn, after Leduc.)

(within the ovum) as the *sperm-* and *germ-nuclei*, or the *male* and *female pronuclei*. In fertilisation these blend with one another, and the ovum then again

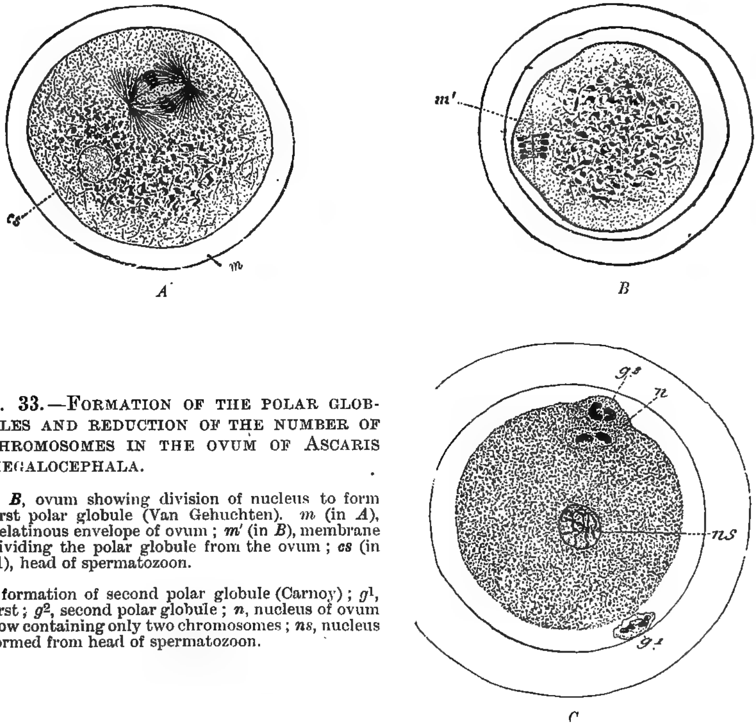

FIG. 33.—FORMATION OF THE POLAR GLOBULES AND REDUCTION OF THE NUMBER OF CHROMOSOMES IN THE OVUM OF ASCARIS MEGALOCEPHALA.

A, *B*, ovum showing division of nucleus to form first polar globule (Van Gehuchten). *m* (in *A*), gelatinous envelope of ovum ; *m'* (in *B*), membrane dividing the polar globule from the ovum ; *cs* (in *A*), head of spermatozoon.

C, formation of second polar globule (Carnoy) ; g^1, first ; g^2, second polar globule ; *n*, nucleus of ovum now containing only two chromosomes ; *ns*, nucleus formed from head of spermatozoon.

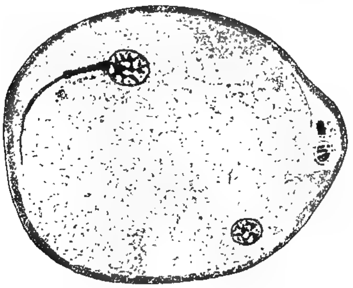

FIG. 34.—OVUM OF BAT WITH POLAR BODIES AND GERM- AND SPERM-NUCLEI. (Van der Stricht.)

The development of the sperm-nucleus from the head of the spermatozoon is very evident in this case, because the rest of the spermatozoon happens not to have been thrown off.

contains a nucleus with the number of chromosomes normal to the species. When it divides each daughter cell is found to contain the normal or somatic number of chromosomes, derived from the splitting of both male and female elements, half the number from the one, and half from the other.

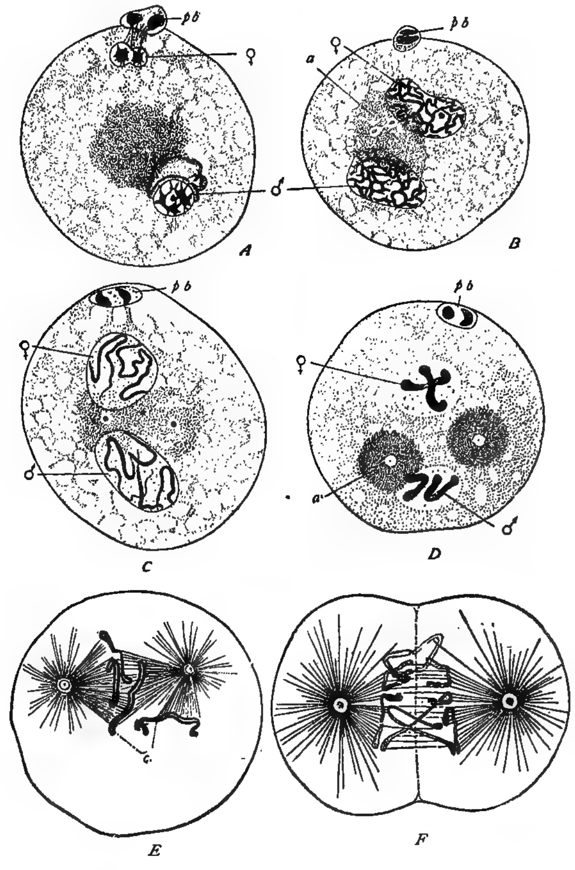

Fig. 35.—Fertilisation and first division of ovum of Ascaris megalocephala (slightly modified from Boveri).

A, second polar globule just formed; the head of the spermatozoon is becoming changed into a reticular pro-nucleus (♂), which shows indistinctly two chromosomes; just above it, its archoplasm is shown: the egg pro-nucleus (♀) also shows two chromosomes.

B, both pro-nuclei are now reticular and enlarged; a double centrosome (*a*) is visible in the archoplasm which lies between them.

C, the chromatin in each pro-nucleus is now converted into two filamentous chromosomes; the centrosomes are separating from one another.

D, the chromosomes are more distinct and shortened; the nuclear membranes have disappeared; the attraction-spheres are distinct.

E, mingling of the four chromosomes (*c*) each of which is seen to be splitting longitudinally; the achromatic spindle is fully formed.

F, separation (towards the poles of the spindle) of the halves of the split chromosomes, and commencing division of the cytoplasm. Each of the daughter cells now has four chromosomes; two of these have been derived from the ovum pro-nucleus, two from the spermatozoon pro-nucleus.

Formation of the tissues.—It appears to be established beyond doubt that new cells can only be formed from pre-existing cells. In the early embryo the whole body is an agglomeration of cells. These have all been formed from the *ovum* or *egg-cell* (fig. 36), which, after fertilisation, divides first into two cells, these again into two, and so on until a large number of cells (embryonic cells) are produced (fig. 37). These form at first an outer clear stratum lying at the surface (fig. 37, *sz*), and a darker granular mass (*i*) attached to this layer at one part, but elsewhere separated from it by clear fluid. Eventually the cells of the inner mass arrange themselves in the form of a membrane (*blastoderm*), which is composed of three layers. These layers are known respectively as the *ectoderm*, *mesoderm*, and *entoderm* (fig. 38). The ectoderm gives rise to most of the epithelial tissues, and to the tissues of the nervous system; the entoderm to the epithelium of the alimentary canal (except the mouth), and the glands in connexion with it; and the mesoderm to the connective and muscular tissues.

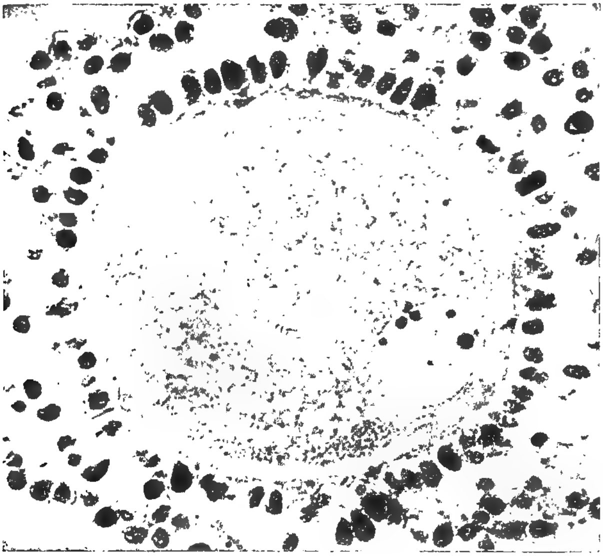

FIG. 36.—OVARIAN OVUM OF RABBIT. Magnified 400 diameters.

The ovum is enclosed within a clear thick membrane (zona pellucida) outside of which, and adhering to it, are epithelium cells of the Graafian follicle. The protoplasm of the ovum shows numerous fine granules and a certain number of large clear yolk globules. The nucleus or germinal vesicle lies near the periphery: it contains several globules of chromatin, the largest of which is the nucleolus or germinal spot.

The tissues are formed either by changes which occur in the intercellular substance, or by changes in the cells themselves; frequently by both these processes combined. Amongst the cells which are least altered from their embryonic condition are the white corpuscles of the blood; these are regarded as typical free cells.

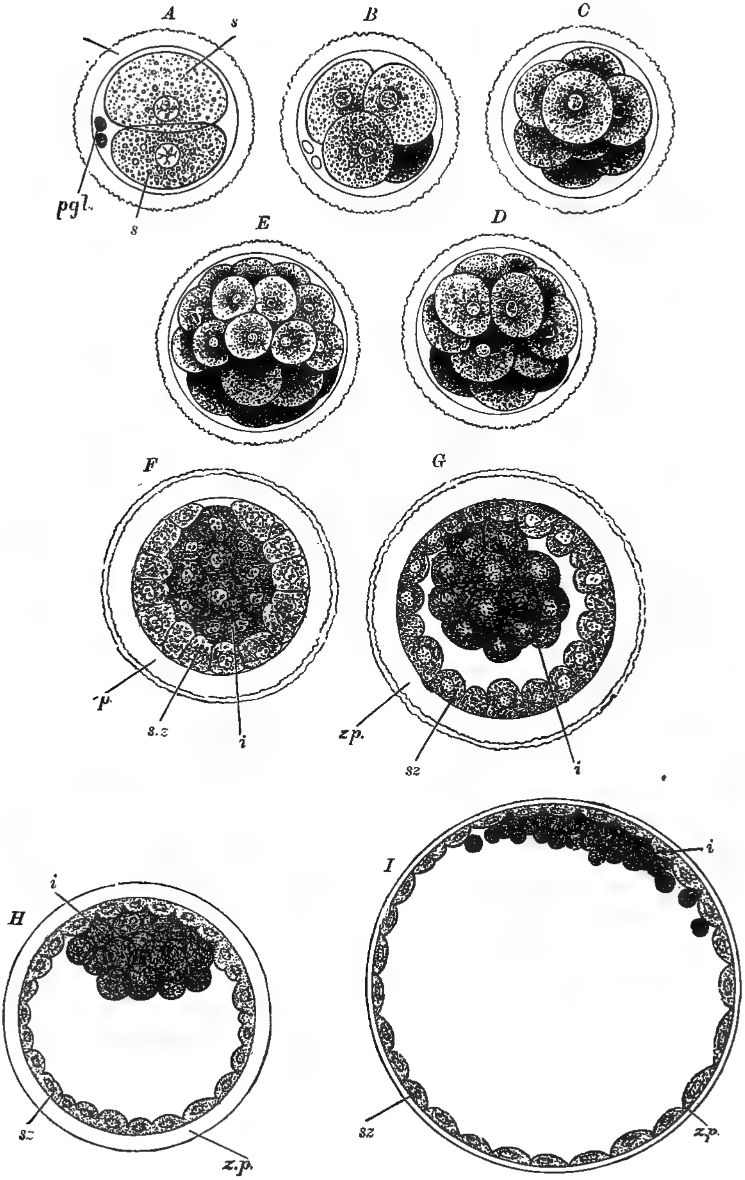

FIG. 37.—FORMATION OF BLASTODERMIC VESICLE IN RABBIT. (Allen Thomson, partly after E. v. Beneden.)

A to *E*, division of ovum and formation of "mulberry mass"; *pgl*, polar globules; *s*, *s*, cells of primary division which already show a difference of appearance. This early differentiation is not, however, accepted by most authorities. *F* to *I*, sections of the ovum in subsequent stages. *zp*, membrane of ovum (zona pellucida); *sz*, subzonal layer, by means of which the ovum becomes attached to the uterine mucous membrane; *i*, inner cell-mass, which gives rise to the blastodermic layers. The accumulation of fluid in *G*, *H*, and *I* has swollen the ovum out to form the so-called blastodermic vesicle.

The histogenetical relation between the three layers of the blastoderm

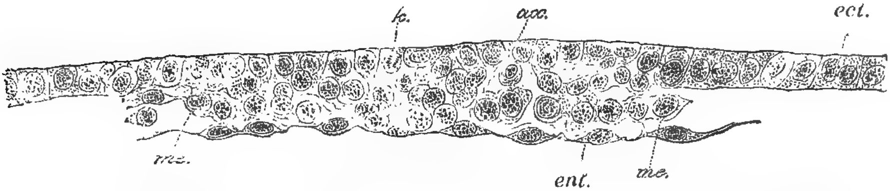

FIG. 38.—SECTION OF BLASTODERM SHOWING THE COMMENCING FORMATION OF THE MESODERM. (Kölliker.)

ect, ectoderm; *ent*, entoderm; *me*, mesoderm; *ax*, axial part of ectoderm with cells undergoing division (*k*). The mesoderm is growing from this part.

and the several tissues and organs of the body is exhibited in the following table:—

Ectoderm.	The epithelium of the skin (epidermis) and its appendages, viz., the hairs, nails, sebaceous and sweat glands, and mammary glands. The muscular fibres of the sweat glands.
	The epithelium of the mouth, and the epithelium of the anus and anal canal. The salivary and other glands which open into the mouth. The enamel of the teeth. The gustatory organs.
	The epithelium of the lower part of the urethra.
	The epithelium of the lower part of the vagina.
	The epithelium of the nasal passages, and of the cavities and glands which open into them.
	The epithelium covering the front of the eye. The epithelium of the lacrimal canals and lacrimal glands. The crystalline lens. The retina. The pars ciliaris retinæ and the pars iridica retinæ. The sphincter and dilatator pupillæ muscles.
	The epithelium lining the membranous labyrinth of the ear. The epithelium lining the external auditory meatus.
	The epithelium lining the central canal of the spinal cord, the aqueduct and the fourth, third, and lateral ventricles of the brain.
	The tissues of the nervous system including all nerve-cells and fibres and neuroglia-cells.
	The pituitary body. The pineal gland. The medulla of the suprarenal capsules.
Mesoderm.	All the connective tissues.
	The blood and lymph-corpuscles.
	The spleen and lymph glands.
	The cortex of the suprarenal capsules.
	The endothelial lining of the heart, blood-vessels, lymphatics, and serous membranes.
	The epithelium of the uriniferous tubules, and that of the ureters and renal pelves.
	The epithelium of the male generative organs, including that of the testis and its ducts, and that of the prostatic vesicle, as well as the male generative cells (spermatozoa).
	The epithelium of the ovary and Graafian follicles, including the female generative cells (ova); the epithelium of the Fallopian tubes, and uterus, and the upper part of the vagina.
	The muscular tissues, voluntary, involuntary and cardiac.
Entoderm.	The epithelium of the alimentary canal (from the pharynx to the lower end of the rectum) and of all the glands which open into it (including the liver and pancreas).
	The epithelium of the Eustachian tube and cavity of the tympanum.
	The epithelium of the larynx, trachea, and bronchi, and of all their ramifications.
	The epithelium of the pulmonary alveoli.
	The thyroid body and parathyroids. The reticulum and the concentric corpuscles of the thymus gland.
	The epithelium of the urinary bladder, of the female urethra, and of the lower part of the vagina.
	The epithelium of the proximal part of the male urethra and its glands.

All the connective tissues, the endothelium of the lymphatic and hæmal systems, and the vascular and lymph glands are formed from a special part of the mesoderm termed *mesenchyme*, which, at an early stage of development, consists of a syncytium of branched cells with a homogeneous intercellular matrix. Plain muscular tissue is for the most part also formed from mesenchyme, but in certain situations, as in the sweat glands and muscular tissue of the iris, it is said to be ectodermal in origin. The generative cells (gonads) in both sexes, although developed in connexion with the mesoderm, are produced from special cells which are early differentiated from the ordinary or somatic cells.

LESSON I.

USE OF THE MICROSCOPE. EXAMINATION OF CERTAIN COMMON OBJECTS.

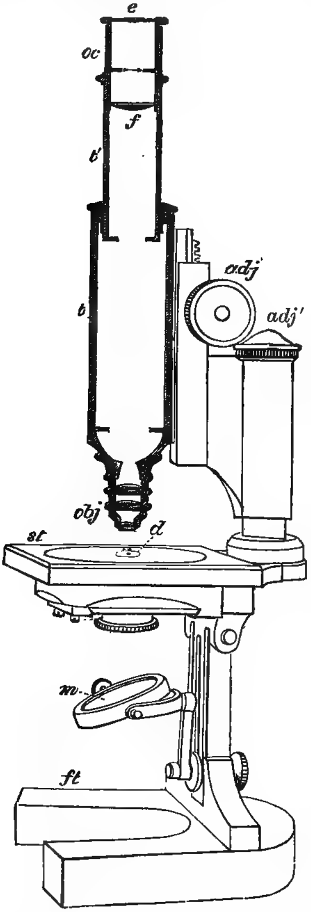

Fig. 39.—Diagram of microscope.

The requisites for practical histology are a good compound microscope ; slips of glass technically known as "slides," upon which the preparations are made ; pieces of thin glass used as covers for the preparations ; a few instruments, such as microtome, scalpel, scissors, forceps, and needles mounted in wooden handles ; and a set of fluid reagents for mounting and staining microscopic preparations.[1] A sketch-book and pencil are also necessary, and must be constantly employed.

The microscope (fig. 39) consists of a tube (*t t'*) 160 millimeters (6·4 inches) long having two systems of lenses, one at the upper end termed the "eye-piece" or "ocular" (*oc*), the other at the lower end termed the "objective" (*obj*). For ordinary work there should be at least two objectives—a low power working at about 8 millimeters (⅓ inch) from the object, and a high power, having a focal distance of about 3 millimeters (⅛ inch) ; it is useful also to have a lower power (commanding a larger field of view) for finding objects readily, and two or more oculars of different magnification. The focus is obtained by cautiously bringing the tube and lenses down towards the object by the coarse adjustment, which is usually a rack-and-pinion movement (*adj*), and focussing exactly by the fine adjustment, which is always a finely cut screw (*adj'*).

The stage (*st*) upon which the preparations are placed for examination, the mirror (*m*) which serves to reflect light up through the central aperture in the stage and along the tube of the instrument, and the diaphragm (*d*) below the stage which is used to regulate the amount of light thus thrown up, are all parts the employment of which is readily understood. A substage condenser (not shown in the diagram), which serves to concentrate the light thrown up by the mirror to the centre of the object, is valuable when high powers and stained preparations are employed.

The combinations of objectives and oculars above referred to will generally give a magnifying power of from 50 to 400 diameters, and this is sufficient for most purposes of histology. But to bring out minute points of detail in the structure of cells and of certain tissues examination with much higher magnifying powers may be necessary. Objectives of high power are usually made as immersion-lenses ; *i.e.* they are con-

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[1] The directions for making the principal fluids used in histological work will be found in the Appendix.

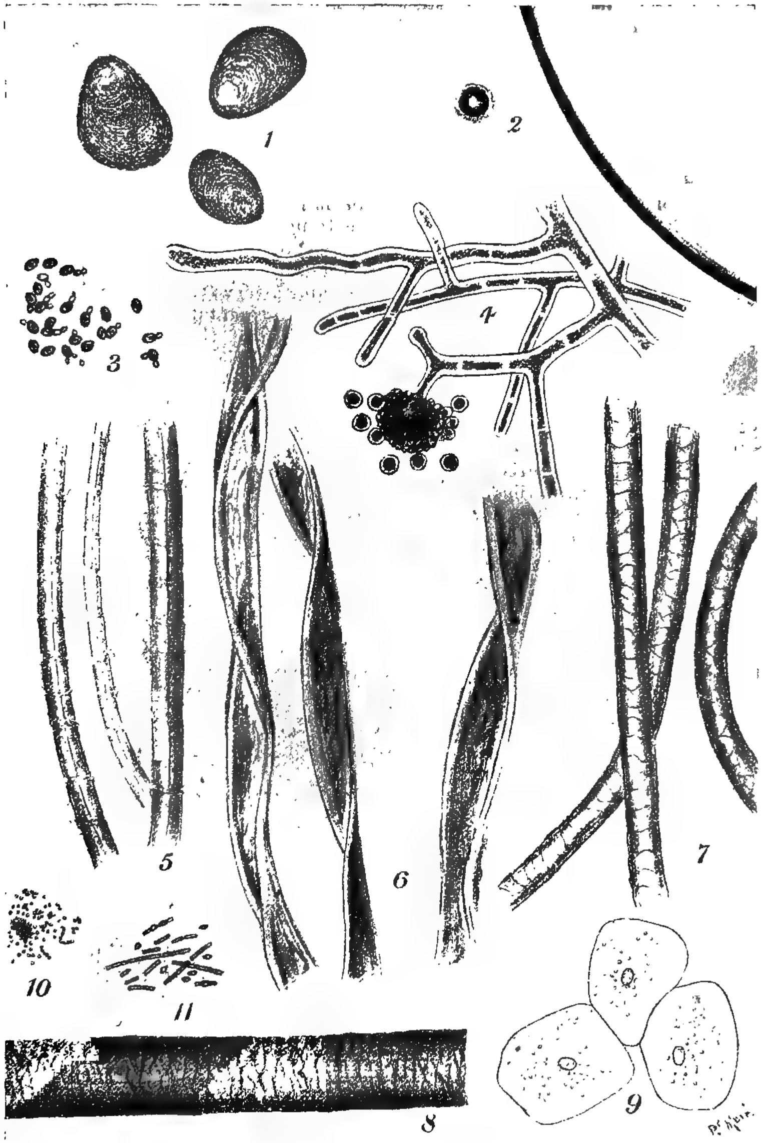

FIG. 40.—OBJECTS WHICH MAY BE ACCIDENTALLY PRESENT IN MICROSCOPE PREPARATIONS.

1, Starch-granules ; 2, a small air bubble and part of a large one ; 3, yeast torulæ ; 4, a mould (*Aspergillus glaucus*) ; 5, linen fibres ; 6, cotton fibres ; 7, wool ; 8, hair, human ; 9, epithelium scales ; 10, micrococci ; 11, bacilli and spores (*B. subtilis*). Magnified about 250 diameters.

structed to form a proper image of the object when the lowermost lens of the system is immersed in a layer of liquid which lies on the cover-glass of the object and has a refractive index not far removed from that of the glass itself. For this purpose an essential oil (oil of cedar-wood) is used. The advantages obtained by the employment of these oil-immersion lenses are:—increased working distance from the object, increased angle of aperture with sharper definition of the object, and increased amount of light traversing the microscope.

The best lenses for histological work are made of the so-called "apochromatic" glass; specially constructed "compensation" eye-pieces are used with these.

A scale for measuring objects should be constructed for each microscope. To do this, put a stage-micrometer (which is a glass slide ruled in the middle with lines $\frac{1}{10}$ and $\frac{1}{100}$ millimeter apart) under the microscope in such a manner that the lines run from left to right (the microscope must not be inclined). Focus them exactly. Put a piece of white card on the table at the right of the microscope. Look through the instrument with the left eye, keeping the right eye open. The lines of the micrometer will appear projected upon the paper. Mark their apparent distance with pencil upon the card, and afterwards make a scale of lines in ink, of the same interval apart. A magnified representation is thus obtained of the micrometer scale. Mark upon it the number of the eye-piece and of the objective, and the length of the microscope-tube. This scale-card will serve for the measurement of any object without the further use of the micrometer. To measure an object, place the scale-card upon the table to the right of the microscope and view the object with the left eye, keeping the right eye open. The object appears projected upon the scale, and its size in $\frac{1}{10}$ or $\frac{1}{100}$ of a millimeter can be read off. It is essential that the same objective and eye-piece should be employed as were used in making the scale, and that the microscope tube should be of the same length. The lines on English stage-micrometers are usually ruled $\frac{1}{100}$ and $\frac{1}{1000}$ inch apart.[1]

Before beginning the study of histology the student should endeavour to familiarise himself with the use of the microscope, and at the same time learn to recognise some of the chief objects which are liable to occur accidentally in microscope specimens. On this account it has been considered desirable to introduce directions for the examination and recognition of starch-granules, moulds and torulæ, air-bubbles, linen, cotton, and woollen fibres, and the usual constituents of the dust of a room (fig. 40).

1. Examination of starch-granules. Gently scrape the cut surface of a potato with the point of a knife; shake the starch-granules so obtained into a drop of water upon a clean slide and apply a cover-glass.

With the low power the starch-granules look like dark specks differing considerably in size; under the high power they are clear, flat, ovoid particles (fig. 40, 1), with a sharp outline when exactly focussed. Notice the change in appearance of the outline as the microscope is focussed up and down. On close examination fine concentric lines are to be seen in the granules, arranged around a minute spot which is generally placed eccentrically near the smaller end of the granule. Sketch two or three starch-granules.

Notice the appearance of air-bubbles in the water (fig. 40, 2). If comparatively large they are clear in the middle, with a broad dark border due to refraction of the light; if small they may look entirely dark.

Pass a drop of dilute iodine solution under the cover-glass, and observe the staining of the starch-granules.

2. Examine some yeast which has been grown in solution of sugar. Observe the yeast-particles or torulæ, some of them budding (fig. 40, 3). Each torula contains a clear vacuole, and has a well-defined outline, due to a membrane. Sketch two or three torulæ.

3. Examine some mould in water. Notice the long branching filaments

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[1] For the method of measuring with an ocular micrometer, and for determining the magnifying power of a microscope, the reader is referred to the author's *Course of Practical Histology.*

(hyphæ), and also the torula-like particles (spores) from which hyphæ may in some instances be seen sprouting (fig. 40, 4). Sketch part of a hypha.

4. Examine fibres of linen and of cotton in water, using a high power. Compare the well-defined, rounded, relatively straight or but slightly twisted linen, with the longer, broader but thinner, and more twisted cotton fibres (fig. 40, 5, 6). Sketch one of each kind.

5. Mount one or two hairs from the head in water and look at them first with the low, then with the high power (fig. 40, 8). Examine also fibres from any woollen material and compare them with the hairs. They have the same structure, although the wool is finer and is curled (fig. 40, 7) ; its structure may be obscured by the dye. Draw one or two of each.

6. Examine a drop of hay infusion, which has been standing a day or two, for bacteria and other putrefactive organisms (fig. 40, 10, 11). The active movements which these exhibit are due to minute cilia or flagella, which can only be made visible by special staining methods and a very high magnifying power. Notice that all very minute particles, organic or inorganic, which occur in fluids may be seen to exhibit the peculiar tremulous dancing movement which is known as the "Brownian" movement.

7. Examine some dust of the room in water with a high power. In addition to groups of black particles of carbon (soot) there will probably be seen fibres of linen, cotton, or wool, and shed epithelium-cells (fig. 40, 9) derived from the epidermis.

8. Examine a drop of milk with the high power. Notice the particles of cream. Their fatty nature is shown by their high refracting power, and by their staining reactions with certain special reagents, such as osmic acid or Soudan III.

LESSONS II. AND III.

STUDY OF THE HUMAN BLOOD-CORPUSCLES.

1. HAVING cleaned a slide and cover-glass, prick the finger above the nail or on the pulp, and mount the small drop of blood which issues from the prick as quickly as possible, so that it has time neither to dry nor to coagulate. Examine it at once with the high power.

Note (*a*) the coloured corpuscles mostly in rouleaux and clumps, but some lying apart seen flat or in profile ; (*b*) the colourless corpuscles, easily made out if the cover-glass is touched by a needle, on account of their tendency to stick to the glass, whilst the coloured corpuscles are driven past by the currents set up ; (*c*) in the clear spaces, fibrin-filaments and elementary particles or blood-platelets.

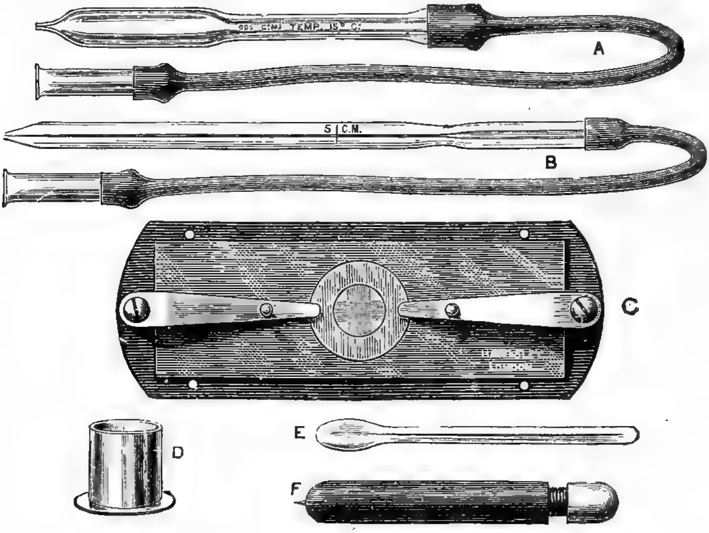

FIG. 41.—HÆMACYTOMETER OF GOWERS.

A, pipette for diluting fluid ; *B*, pipette for blood ; *C*, slide ; *D*, mixing bowl ; *E*, mixer *F*, needle for pricking finger.

Sketch a roll of coloured corpuscles and one or two colourless corpuscles. Count the number of colourless corpuscles in a field of the microscope.

2. To be made as in § 1, but the drop of blood is to be mixed upon the slide with an equal amount of normal or isotonic saline[1] so that the red corpuscles tend to be less massed together, and their peculiar shape is better displayed.

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[1] A solution of sodium chloride containing from 7·5 to 9 grammes to the litre for mammals, 6 grammes for the frog. Ringer's solution may also be used. This is made by saturating normal saline with calcium phosphate, and adding 10 milligrammes of potassium chloride to each litre. (See also Appendix).

Sketch a red corpuscle seen on the flat and another in profile (or optical section). Also a crenated corpuscle.

Measure ten red corpuscles, and from the results ascertain the average diameter of a corpuscle. Measure also the largest and the smallest you can find.

3. Make a preparation of blood as in § 1 and put it aside to coagulate. Keep the edges from drying by placing it in a moist chamber or by occasionally breathing upon it. After a few minutes place a drop of 1 per cent. methyl violet at one edge of the cover and allow this to pass in and mix with the blood: it may be drawn through the preparation by applying a very small fragment of blotting paper to the opposite edge. The dye stains the nuclei of the white corpuscles, the blood-platelets, the network of fibrin-filaments, and the membranes of the red blood-corpuscles.

The three preparations just described cannot be kept, but the two following will serve as permanent preparations of blood :—

4. To fix and stain the coloured corpuscles:—Place upon a slide a drop of 1 per cent. osmic acid mixed with an equal amount of saturated aqueous solution of eosin. Prick the finger, and mix the blood directly with the coloured fluid, stirring them together with a needle. Cover the mixture and put aside for an hour, protected from evaporation ; then place a very small drop of glycerine and water at the edge of the cover-glass. When this has passed under, *i.e.* in about half an hour or more, fix the cover-glass with gold size.

5. To study the granules of the colourless corpuscles and their reactions to different staining reagents, a film of blood is enclosed between two cover-glasses which are at once separated and the film on each quickly dried in the air. A slide may be used instead of a cover-glass ; the drop of blood is placed close to the ground edge of one slide and this is drawn evenly over the middle of another. The films are fixed by immersion for one hour or more in a mixture of alcohol and ether, equal parts of each ; or for four minutes in a mixture of 10 parts formol and 90 absolute alcohol. The film is then stained by (1) a saturated solution of eosin in 75 per cent. alcohol (three minutes), after which it is rinsed with water, and treated with (2) a 1 per cent. solution of methylene blue (one minute). The film is again rinsed with water, rapidly dried, and mounted in dammar.

Combined eosin-methylene blue stains, such as Jenner's or Leishman's, may also be employed for films. These require only one operation (see Appendix).

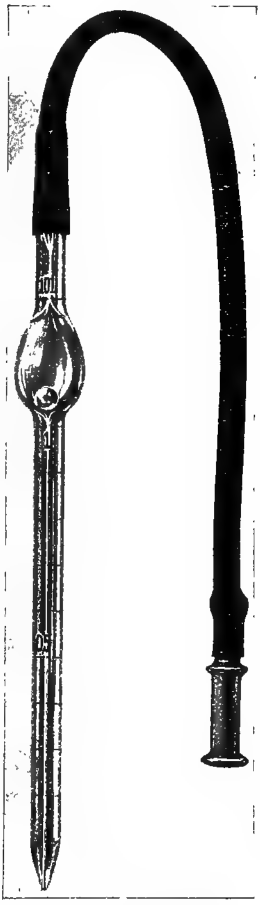

FIG. 42.—PIPETTE USED FOR THE THOMA-ZEISS HÆMACYTOMETER.

6. Mount in dammar sections of marrow from a long bone (rabbit) fixed with mercuric chloride or formol and stained with eosin and methylene blue. Observe the fat-cells, the supporting reticular tissue, the proper marrow-cells in this tissue, the myeloplaxes and the erythroblasts.

7. Tease in salt solution or serum some of the red marrow from the rib of a recently-killed animal. Observe and sketch the proper marrow-cells (myelocytes) and look for myeloplaxes (giant cells) and nucleated coloured blood-corpuscles (erythroblasts).

8. Make a film preparation of red marrow by smearing a little upon a cover-glass or slide, allowing it to dry quickly, and placing it in the above mixture of formol and alcohol. After a few minutes in this, the preparation may be stained with eosin and methylene blue or by Leishman's stain in exactly the same way as a film preparation of blood (see § 5), and mounted in dammar.

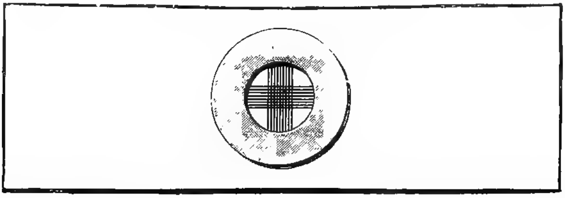

FIG. 43.—HÆMACYTOMETER SLIDE, RULED IN SQUARES FOR THE ENUMERATION OF BLOOD-CORPUSCLES.

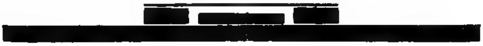

FIG. 44.—DIAGRAM OF A SECTION THROUGH THE HÆMACYTOMETER SLIDE.

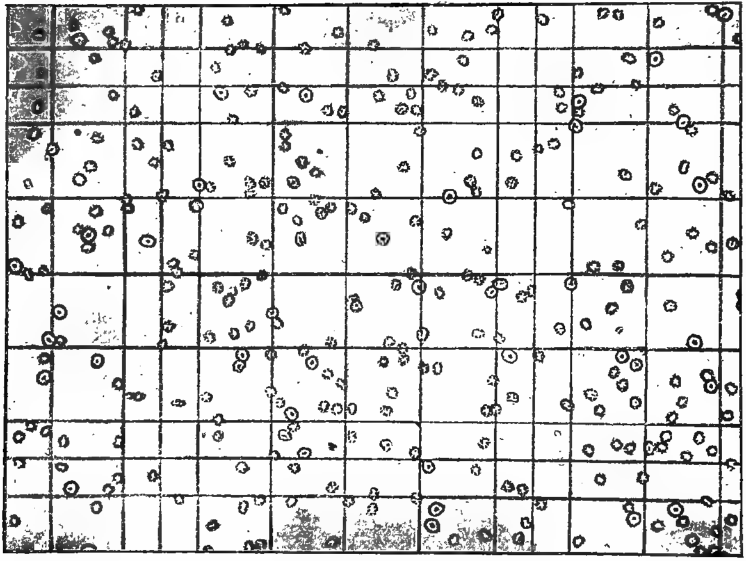

FIG. 45.—APPEARANCE OF THE SQUARES OF THE THOMA-ZEISS HÆMACYTOMETER WHEN USED FOR A BLOOD-COUNT. Magnified 200 diameters.

9. Enumeration of the blood-corpuscles. This is done by some form of blood counter such as the hæmacytometer of Gowers, or the similar apparatus of Thoma. In Gower's apparatus (fig. 41), one pipette is used for measuring the blood and another for the diluting fluid, and the mixture is made in a small glass vessel with the aid of a glass rod ; these are easier to clean than the combined measuring and mixing pipette of the Thoma apparatus (fig. 42). The latter is however more generally used. For purposes of counting, the Thoma-Zeiss instrument is provided with a

glass slide (figs. 43, 44), the centre of which is occupied by a small glass plate having its upper surface ruled into $\frac{1}{10}$ mm. squares, subdivided into smaller portions to facilitate enumeration, and surrounded by a glass ring $\frac{1}{10}$ mm. thicker than the ruled glass plate. In Gower's instrument, the ruling is usually in $\frac{1}{5}$ mm. squares with a ring $\frac{1}{5}$ mm. thick. The diluting solution may either be that of Hayem, viz., distilled water 200 c.c., sulphate of soda 5 gms., common salt 1 gm., corrosive sublimate 0·5 gm., or that of Marcano, viz, 97 c.c. of a solution of sulphate of soda (in distilled water) of sp. gr. 1020, to which is added chloride of sodium 1 gm., and formol 3 c.c. The finger is pricked, and the pipette (fig. 42) filled with blood exactly up to the 1 mark. The pipette is then filled with diluting solution up to the 101 mark, the blood being thereby drawn up into the mixing vessel, where it is thoroughly mixed with the solution by shaking the included glass ball. It is thus diluted 100 times. After expelling the clean fluid in the capillary part, a drop of the mixture is placed in the centre of the cell, and the cover-glass is gently laid on so as to touch the drop, which thus forms a layer $\frac{1}{10}$ mm. thick between the ruled glass plate and cover-glass. In a few minutes the corpuscles have sunk to the bottom of the layer of fluid and rest on the squares (fig. 45). The number in ten of the $\frac{1}{10}$ mm. squares is then counted, and this, multiplied by 100, gives the number in a cubic millimeter of the mixture, or if again multiplied by 100 (the amount of dilution) the number in a cubic millimeter of blood.

For the enumeration of the white corpuscles the blood is diluted only 10 times instead of 100 times. It is also convenient to use one half per cent. solution of acetic acid just coloured with methyl violet as a diluent (Thoma). This destroys the coloured corpuscles and stains the nuclei of the white.

The coloured blood-corpuscles.—The coloured corpuscles are composed of a delicate colourless highly elastic (? protoplasmic) *envelope*, and *coloured fluid contents*, consisting mainly of a solution of hæmoglobin. The existence of an envelope is shown by the osmotic effects of water and solutions of salt upon the corpuscle. The description which was formerly current that the red corpuscles consist of a porous solid *stroma*, permeated with dissolved hæmoglobin, is incompatible with these phenomena. Moreover, the envelope can be distinctly seen with the microscope, especially in the amphibian corpuscle, and can be stained by reagents. The envelope contains lipoid substances (lecithin and cholesterol); these substances seem to impart a certain greasiness to the surface of the corpuscle. It is probably due to this that the corpuscles run together into rouleaux when the blood comes to rest (see p. 49).

Under the microscope blood is seen to consist of a clear fluid (*plasma*), in which are suspended the *blood-corpuscles* (fig. 46). The latter are of two kinds: the *red* or *coloured* (*erythrocytes*), which are by far the more numerous, and the *white*, *pale*, or *colourless* (*leucocytes*). In addition to the more obvious corpuscles, blood contains a variable number of minute particles which were termed by Zimmermann the *elementary particles of the blood*, but which are now usually known as *blood-platelets*.

Erythrocytes.—When seen singly the coloured corpuscles are not distinctly red, but appear of a reddish-yellow tinge. In the blood of man and of all other mammals, except the Camelidæ, they are biconcave circular disks. Their central part usually has a lightly shaded aspect under a moderately high power, but this is due to their biconcave shape, not to the presence of a nucleus. They have, as just stated, a strong tendency to become aggregated into rouleaux and clumps when the blood is at rest, but if it is disturbed they readily become separated.

If the density of the plasma is increased in any way, as by evaporation, many of the red corpuscles become shrunken and crenated by the passage of water out of the corpuscle. On the other hand, a diminution in the density of the plasma tends to cause the red corpuscles to become cup-shaped, but it is erroneous to describe this as the normal form of the corpuscle, although a certain number of cup-shaped corpuscles are, it is true, to be seen in the circulating blood when this is examined in transparent parts of animals. By far the largest number, however, are biconcave.

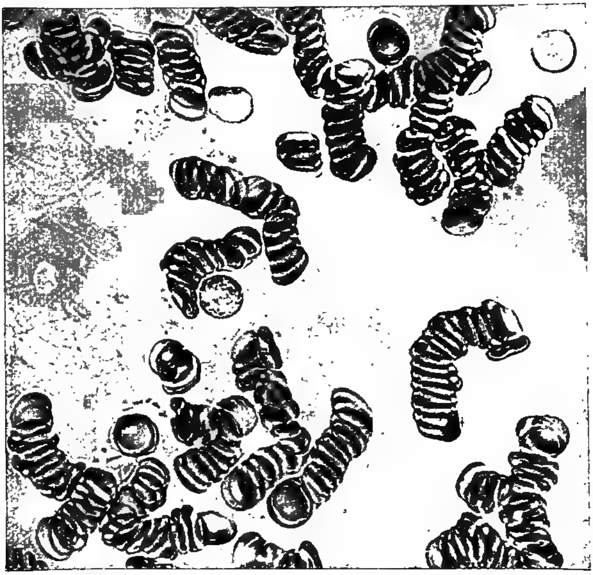

FIG. 46.—HUMAN BLOOD. Photograph. Magnified 650 diameters.

The average diameter of the human red corpuscle is 0·0075 mm.[1] (about $\frac{1}{3200}$ in.), but a few will always be found somewhat larger (0·0085) and a few somewhat smaller (0·0065 mm.).[2]

There are normally from four to five millions of coloured corpuscles in a cubic millimeter of adult human blood.

Leucocytes.—The colourless corpuscles of human blood are protoplasmic cells, averaging 0·01 mm. ($\frac{1}{2500}$ in.) in diameter when spheroidal, but they vary much in size and shape. They are far fewer than the coloured corpuscles, usually numbering not more than eight to ten thousand in a cubic millimeter (about 1 to 600 red corpuscles). They are increased in number by any conditions which tend to increase the rate of circulation. They are specifically lighter than the red corpuscles. If examined immediately the blood is drawn, they are spherical in shape, but soon become flattened and then irregular in form (fig. 3), and their outline continually alters, owing to the amœba-like changes to which they are subject. In some kinds (*phagocytes*) the protoplasm tends to take in foreign particles with which the cells come in contact; in others there seems to be little or no such tendency. Some of the colourless corpuscles are very pale and filled with fine granules, others contain coarser and more distinct granules in their protoplasm; others again have a hyaline protoplasm without any apparent granules. In some corpuscles (*lymphocytes*) the protoplasm forms only a relatively small proportion as compared with the nucleus.

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[1] Also expressed as 7·5 μ or microns ; a micron being $\frac{1}{1000}$ mm.

[2] The following list gives the diameter in parts of a millimeter of the red blood-corpuscles of some of the common domestic animals :—Dog, 0·0073 ; rabbit, 0·0069 ; cat, 0·0065 ; sheep, 0·0050 ; goat, 0·0041.

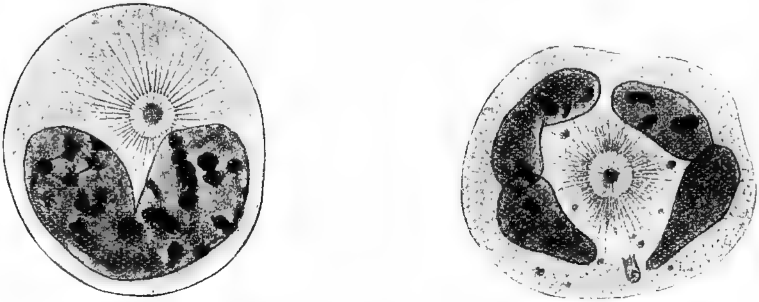

FIG. 47.—TWO LEUCOCYTES OF LEPIDOSIREN, SHOWING ATTRACTION-SPHERE. (T. H. Bryce.)

A, a macrocyte, with kidney-shaped nucleus.
B, a polymorph, with lobed nucleus (the threads of chromatin joining the lobes are not shown).

Leucocytes are classified according to the character and appearance of the nucleus and the nature and staining qualities of the granules in their protoplasm. Some of their granules are readily stained by basic dyes such as methylene blue; such granules are accordingly termed *basiphil*. Distinct coarse basiphil granules are, however, rare in normal blood, although cells with these granules are always present in the marrow and in some connective tissues, and make their appearance in the blood in leucocythæmia. On the other hand, some granules more readily take up colour from acid dyes, such as eosin; these have been termed *oxyphil* or *eosinophil*. Others possess granules (*amphophil*) which are stained by both acid and basic dyes; and others chiefly by neutral dyes (*neutrophil*). In some cells more than one kind of granule is met with. The protoplasm may also contain clear spaces or vacuoles. Each leucocyte has at least one nucleus, which is difficult to see in a fresh preparation, but is easily seen after the action of most reagents and after staining. There is also a centrosome with attraction-sphere (fig. 47).

The following are the chief varieties of leucocytes:—1. *Polymorphocytes.* Cells with lobed or multipartite nuclei and a relatively large amount of protoplasm, which is highly amœboid. These are often termed multi-(poly-) nuclear, but the nucleus is rarely if ever multiple, its several parts being joined by threads of nuclear substance. The cells in question vary in size, but when spherical are usually not quite 0·01 mm. in diameter. Their protoplasm stains with eosin, this being due to the presence of fine oxyphil granules (Kanthack and Hardy). They are highly amœboid and phagocytic, and constitute from sixty to seventy per cent. of all the leucocytes of the blood (fig. 48, *a* ; see also fig. 49).

2. *Lymphocytes.*—These are small cells, with a limited amount of clear protoplasm around the nucleus, which is simple, not lobed or divided (fig. 48, *b*; see also fig. 49, on right). The amœboid phenomena are less marked in them than in the other varieties of leucocyte. The protoplasm stains with methylene blue. They are about 0·0065 mm. in diameter, but some are larger and appear to be transitional between this and the next variety. They constitute from fifteen to thirty per cent. of the total number of leucocytes in the blood. They are relatively more numerous in infancy.

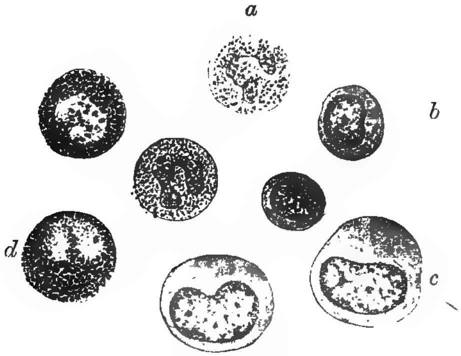

FIG. 48.—VARIOUS KINDS OF COLOURLESS CORPUSCLES, SHOWING THE DIFFERENT CHARACTERS OF THE GRANULES. (From a film preparation of normal human blood.) Two of each kind have been drawn.

3. *Macrocytes.*—Large uninucleated cells similar to the last, but larger, and containing much more protoplasm (fig. 48, *c*; fig. 49, on left). Some are smaller than the rest and may be regarded as transitional forms from the last variety. The nucleus is spherical, oval, or kidney-shaped. The protoplasm is hyaline; it stains slightly with methylene blue, owing to the presence of very fine basiphil granules. These cells are amœboid and phagocytic. Including the transitional forms, they constitute about five per cent. of all the leucocytes in blood.

4. *Oxyphils.*—These are characterised by their coarse granules, which stain deeply with acid dyes, such as eosin. Their average diameter in the

spherical condition is 0·01 mm. The nucleus may be simple or lobed (fig. 48, *d*). They are amœboid, but less actively so than the finely granular cells. They are more variable in number than the other varieties, constituting sometimes not more than one per cent., and at other times as much as ten per cent., of the total leucocytes of blood.

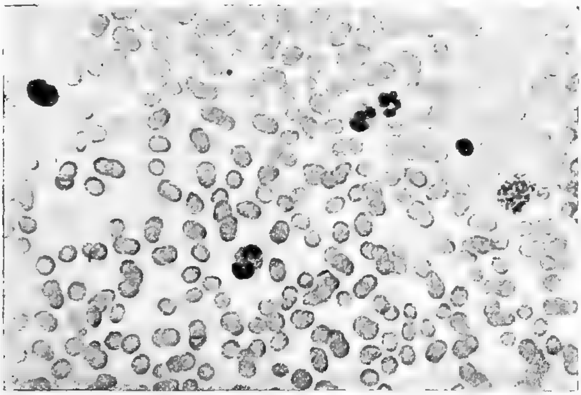

FIG. 49.—BLOOD FILM STAINED WITH HÆMATOXYLIN AND EOSIN.
Magnified 400 diameters.

There are seen in the field, besides numerous red corpuscles, five leucocytes and a mass of blood-platelets (on the right), as well as a few scattered platelets. Of the leucocytes, that on the left is a macrocyte, that on the right a lymphocyte, and the rest polymorphocytes.

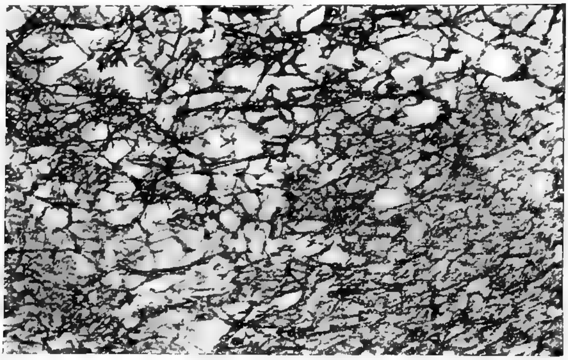

FIG. 50.—NETWORK OF FIBRIN FILAMENTS FROM A SECTION OF BLOODCLOT.
Magnified 400 diameters.

5. *Basiphils.*—These are rarely if ever found in normal blood (adult), but occur in children, and in certain pathological conditions affecting the bone-marrow.

The granules of leucocytes are usually studied in films of blood which are allowed to dry upon a slide, and are then doubly stained with basic and acid dyes. Fig. 49 is a photograph of such a preparation of human blood.

Blood-platelets.—In the clear fluid in which the blood-corpuscles are suspended, a network of fine intercrossing filaments of fibrin soon makes its appearance (fig. 46, on the left). This fibrin network is especially well seen in sections of bloodclot (fig. 50). The filaments often radiate from minute round colourless discoid and often spindle-shaped particles less than one-third the diameter of a red corpuscle, which either lie separately or are collected into groups or masses of variable, sometimes of considerable, size. These are the *elementary particles, blood-platelets,* or *thrombocytes.* In the blood-vessels they are discrete (fig. 51), but they immediately clump together when blood is drawn (fig. 49). If, however, the blood is examined on agar jelly containing certain salts, the platelets can be kept separate. They usually under these conditions spread out into an irregular shape, and may then be stained and submitted to very high powers of the microscope. The result of such examination shows that each one contains a minute particle which stains rather more deeply than the rest of the blood-platelet (fig. 52). This particle has been considered to represent a nucleus, and the blood-platelets have on this ground been regarded as cells (Deetjen). This view is supported by the fact that in Amphibia where the blood-platelets are much larger they unquestionably contain a nucleus. Blood-platelets vary greatly in number: by the employment of methods which prevent their becoming massed together it is found that they average from 200,000 to 300,000 per cubic millimeter of blood.

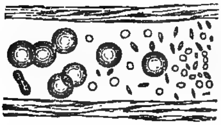

FIG. 51.—BLOOD-CORPUSCLES AND ELEMENTARY PARTICLES OR BLOOD-PLATELETS, WITHIN A SMALL VEIN. (W. Osler.)

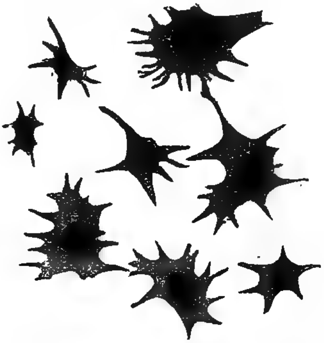

FIG. 52.—BLOOD-PLATELETS, HIGHLY MAGNIFIED, SHOWING THEIR IRREGULAR FORMS WHICH THEY ASSUME WHEN EXAMINED UNDER SUITABLE CONDITIONS, AND ALSO EXHIBITING THE CHROMATIC PARTICLE WHICH EACH PLATELET CONTAINS, AND WHICH HAS BEEN REGARDED AS A NUCLEUS. (After Kopsch.)

The spreading out upon glass or other foreign surface is not analogous to the amœboid movements of the leucocytes, for it is irreversible. It is a pronounced example of thigmotaxis (tendency to adhere to solid substances).

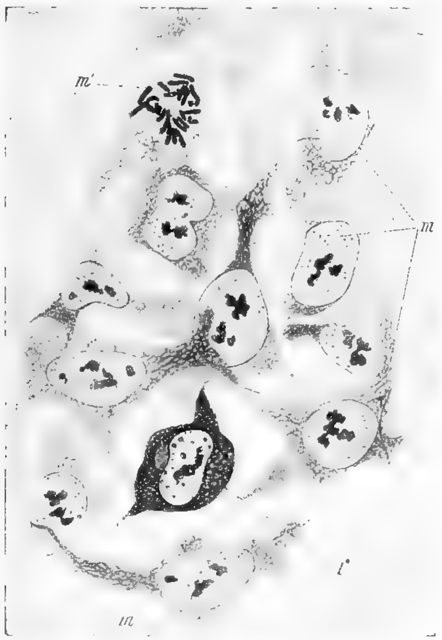

Fig. 53.—Mesoderm cells of rabbit embryo, united to form a syncytium. (Maximow.)

m, ordinary mesoderm cells; *m′*, a cell in karyokinesis; *l*, a primitive blood-cell.

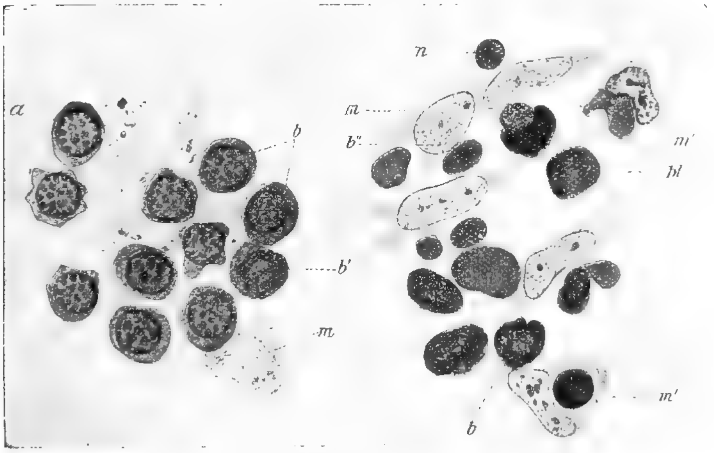

Fig. 54.—Groups of primitive erythroblasts in mesoderm of embryo rabbit. (Maximow.)

a, normoblasts; *b*, *b′*, erythroblasts; *m*, mesoderm cells; *m′*, mesoderm cells containing hæmoglobin; *b″*, extrusion of nucleus from an erythroblast; *n*, an extruded nucleus; *bl*, an erythrocyte.

Cells which exhibit this property to a high degree are termed by J. Tait *thigmocytes*. After blood is drawn, and when it comes in contact with foreign matter or injured tissue, the blood-platelets not only spread out in the manner above-mentioned, but also undergo a further remarkable disintegrative change, giving off viscid threads which adhere together, and fix themselves to adjacent structures. This property will be again referred to when amphibian blood is dealt with.

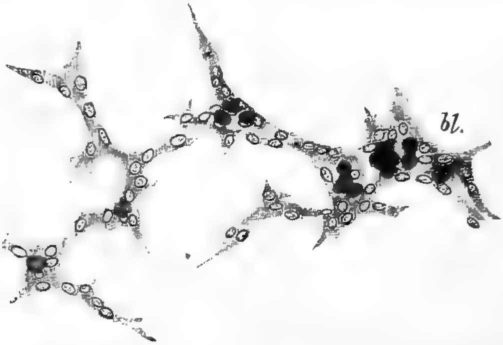

FIG. 55.—DEVELOPMENT OF BLOOD-VESSELS AND BLOOD-CORPUSCLES IN THE VASCULAR AREA OF THE GUINEA-PIG.

bl, blood-corpuscles becoming free in the interior of a nucleated protoplasmic mass.

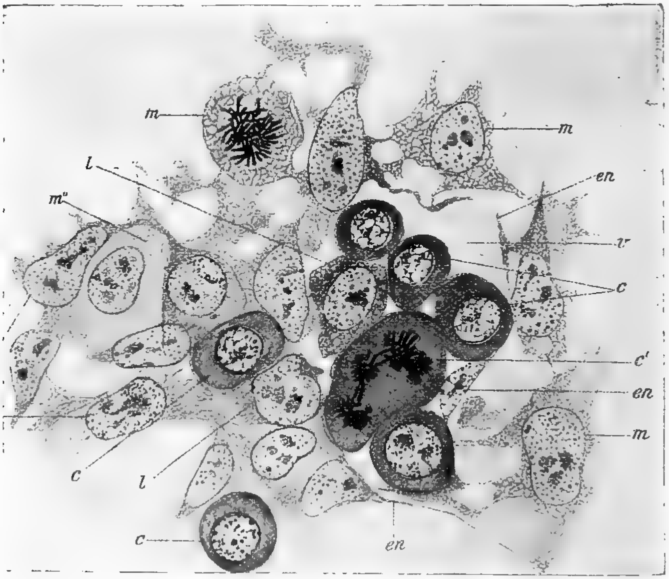

FIG. 56.—DEVELOPMENT OF BLOOD-CORPUSCLES IN RABBIT. (Maximow.)

m, *m'*, *m''*, mesenchymo cells, one showing mitosis; *en*, endothelial cells of vessel; *c*, cavity of vessel; *l*, lymphoblasts; *e*, primitive erythroblasts; *e'*, one in mitosis.

Fatty particles, derived from the chyle, occur in the plasma during absorption of food containing fats.

Development of red blood-corpuscles.—In the mesoderm of the embryo, at first in that of the yolk sac and subsequently in the body of the embryo, the blood-corpuscles make their appearance as amœboid nucleated cells, apparently derived by mitotic division from some of the ordinary mesoderm cells (fig. 53). These are the *blood-cells* or *primitive hæmatoblasts.* They resemble lymphocytes, but after a time the protoplasm of some of them is found to contain hæmoglobin (fig. 54); they may now be termed *primitive erythroblasts.* Soon after their appearance they are found to be enclosed within a syncytium of the mesoderm or mesenchyme (fig. 55), which forms a network, at first incomplete but afterwards complete, at the nodes of which are enlargements containing groups of the primitive erythroblasts. This gives to the tissue the appearance of isolated reddish spots—the *blood-islands*

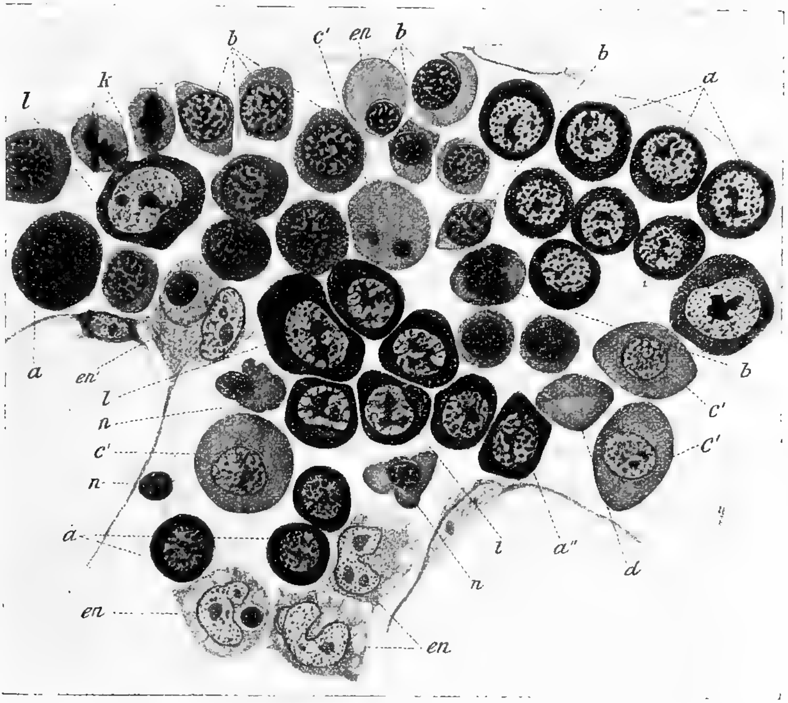

FIG. 57.—PART OF A BLOOD-VESSEL FROM THE YOLK SAC OF THE RABBIT EMBRYO, SHOWING THE CHANGES WHICH OCCUR IN THE PROCESS OF FORMATION OF ERYTHROCYTES. (Maximow.)

a, *a′*, *a″*, megaloblasts; *b*, normoblasts in process of transformation into erythroblasts; *c′*, erythroblasts, the nuclei of which are becoming less chromatic and in one or two cells have almost disappeared; *d*, an erythrocyte fully formed but not discoid; *en*, *en′*, phagocytic endothelial cells; *l*, lymphocytes; *k*, a divided lymphocyte; *n*, erythroblasts somewhat shrunken and with atrophying nucleus; ***n***, a nucleus becoming extruded.

of Pander. The network becomes hollowed out by an accumulation of fluid in the syncytial protoplasm, and thus are produced a number of capillary blood-vessels, within which the coloured nucleated cells are set free as embryonic blood-corpuscles (fig. 55). Within the circulation these multiply by mitotic division, and thus become rapidly more numerous. The primitive erythroblasts are relatively large, and resemble the megaloblasts of bone-marrow (see p. 46), but after division they give rise to smaller erythroblasts, similar to the normoblasts of bone-marrow. These form the nucleated coloured blood-corpuscles (erythroblasts) of the embryo during the first few weeks of intrauterine life. They also multiply by mitotic division, so that the number of nucleated coloured blood-corpuscles becomes considerable, a certain number of colourless cells also appearing amongst them. After a

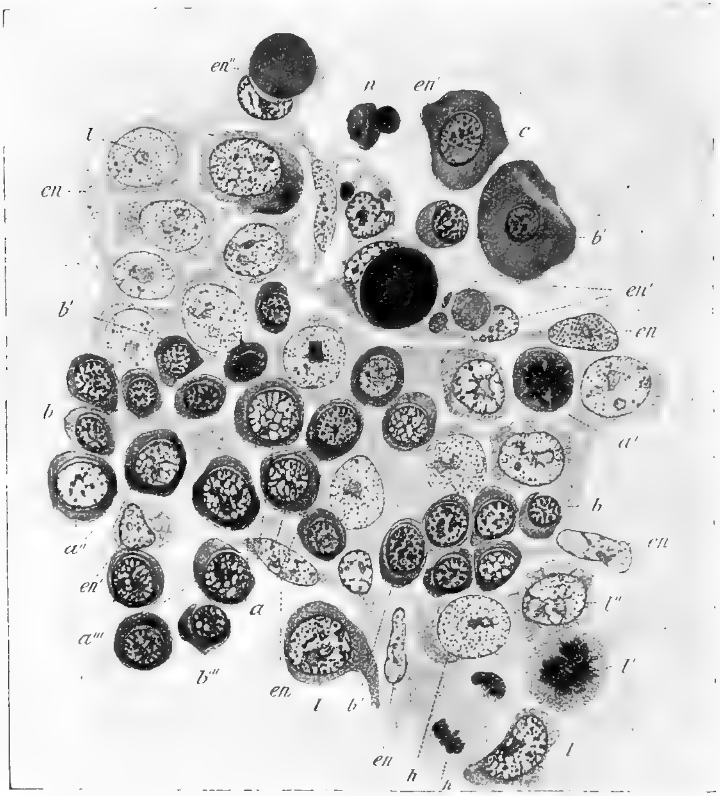

Fig. 58.—Formation of erythroblasts in liver of embryo rabbit. (Maximow.)

en, *en'*, endothelial cells of vessels; *a*, *a'*, *a''*, *a'''*, megaloblasts; *b*, *b'*, *b''*, *b'''*, normoblasts; *c*, erythroblasts; *l*, *l'*, *l''*, lymphoblasts; *h*, hepatic cells; *n*, a nucleus becoming extruded from a small erythroblast.

time, ordinary non-nucleated blood-disks (erythrocytes) of very variable size begin to appear amongst the nucleated cells, and these last become relatively fewer in number. Before the middle of intrauterine life the erythroblasts have nearly disappeared from the blood, and their place is taken, as in the adult, by erythrocytes, the erythroblasts being confined to bone-marrow, and the various changes in them which lead to the development of erythrocytes, now taking place in the marrow instead of in the blood-vessels as is the case in the early embryo (figs. 56, 57).

The multiplication of erythroblasts by mitosis, and the formation from them of erythrocytes, is found to go on in the blood-vessels of the embryonic liver long after it has ceased to be observed in other vessels (fig. 58). According to Maximow it is not confined to the blood-vessels, but goes on also in the hepatic tissue between the vessels. In birds it continues to occur throughout life within the blood-vessels of the bone-marrow.

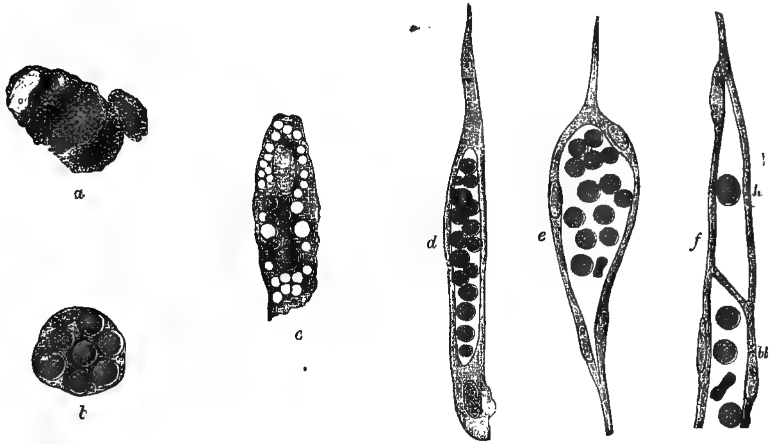

FIG. 59.—BLOOD-CORPUSCLES DEVELOPING WITHIN CONNECTIVE-TISSUE CELLS.

a, a cell containing diffused hæmoglobin; *b*, a cell filled with coloured globules; *c*, a cell containing coloured globules in the protoplasm, within which also are numerous vacuoles; *d*, an elongated cell with a cavity in its protoplasm occupied by fluid and blood-corpuscles mostly globular; *e*, a hollow cell, the nucleus of which has multiplied. The new nuclei are arranged around the wall of the cavity, the corpuscles in which have now become discoid; *f*, shows the mode of union of a "hæmapoietic" cell, which in this instance contains only one corpuscle, with the prolongation (*bl*) of a previously existing vessel.

Erythrocytes are also formed at a somewhat later stage of development within certain cells of the connective tissue (*vasoformative cells*), a portion of the substance of the cell becoming coloured by hæmoglobin, and separated into globular particles (fig. 59, *a*, *b*, *c*), which are gradually moulded into disk-shaped red corpuscles. In the meantime the cells become hollowed out, and join with similar neighbouring cells to form blood-vessels (fig. 59, *d*, *e*, *f*). The process is therefore somewhat different from that in the early embryo since cell-nuclei are not included in the hæmoglobin-holding protoplasm from which the erythrocytes are formed.

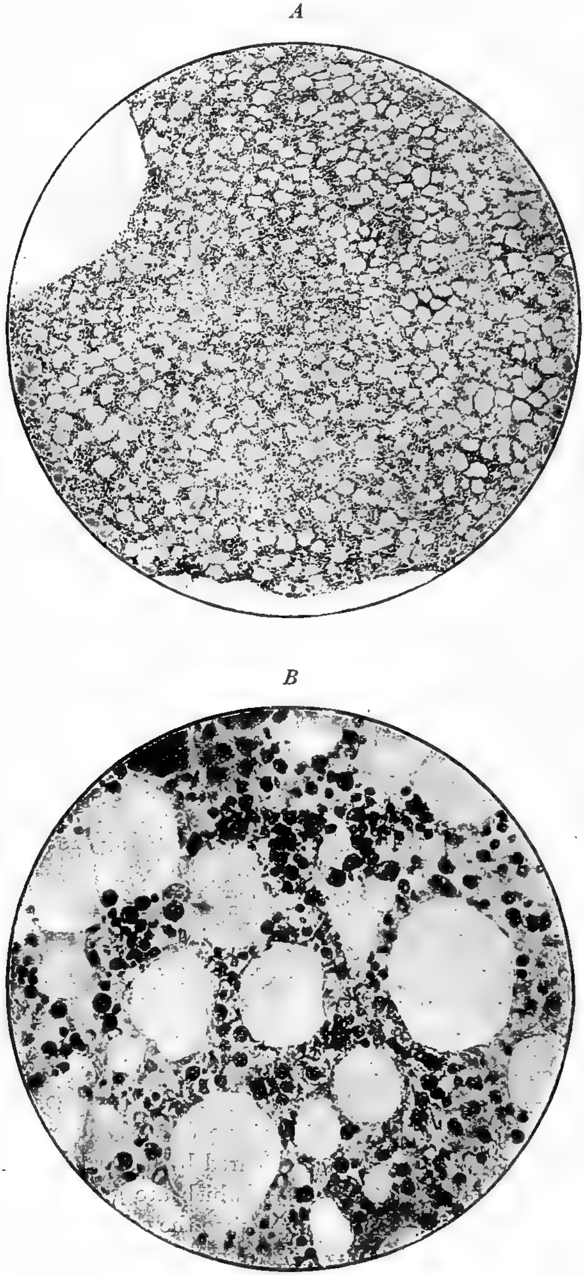

FIG. 60.—SECTIONS OF RED MARROW. (Carnegie Dickson.)

A, Magnified 45 diameters. *B*, Magnified 300 diameters. The clear spaces are due to the presence of fat-cells.

It has been suggested by some writers that the vasoformative cells containing coloured corpuscles in various stages of formation are in reality portions of an already formed vascular network which is undergoing atrophy; and that the corpuscles within such cells are not in process of formation but of disappearance. But since the appearances in question are seen in parts in which vascular tissues (such as fat) are undergoing not atrophy but formation; and since, moreover, the hæmatoidin crystals and pigment granules which are characteristic of the disintegration of erythrocytes within cells are not present, it seems more reasonable to interpret the appearances as indicative of intracellular development of blood-corpuscles by differentiation of part of the protoplasm of the vasoformative mesenchyme cell, rather than as a degeneration of already formed blood-vessels and blood-corpuscles.

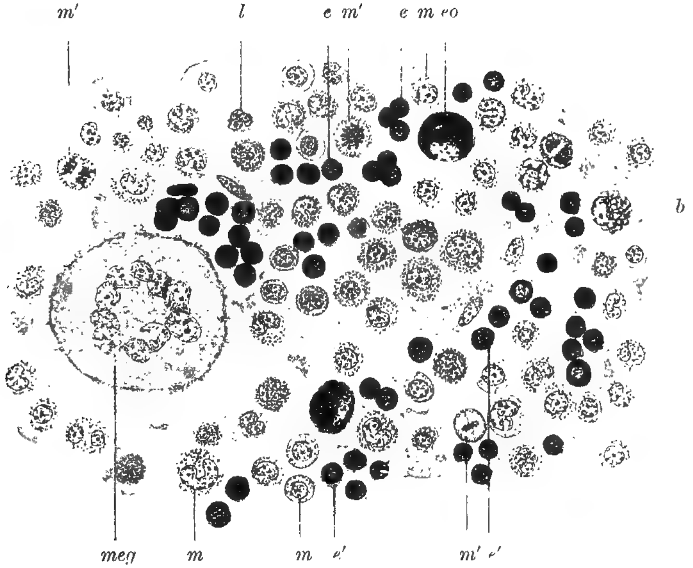

FIG. 61.—RED MARROW OF YOUNG RABBIT. Magnified 450 diameters.

e, erythrocytes; *e'*, erythroblasts; *e''*, a coloured cell undergoing mitotic division; *l*, a polymorph leucocyte; *m*, ordinary myelocytes; *m'*, myelocytes undergoing mitotic division; *eo*, an eosinophil myelocyte; *b*, a basiphil myelocyte; *meg*, a giant-cell or megakaryocyte.

Formation in bone-marrow.—The marrow of bone is of a yellow colour in the shafts of the long bones of most animals, and is there largely composed of adipose tissue, but in the shafts of the long bones of some animals, and in the cancellated tissue of most, it has relatively few fat-cells, and is usually red, the colour being mainly due to the large amount of blood in its vessels. This red marrow (figs. 60, 61) is chiefly composed of protoplasmic cells—the *myelocytes* or *marrow-cells*—which resemble rather large blood-leucocytes, and, like these, are amœboid. They also exhibit the same kind of differences as to the character of the granules which they contain, some being oxyphil and others amphophil or neutrophil. But while the blood-leucocytes rarely contain any coarse basiphil granules, some of the marrow-cells contain these in considerable numbers. There are also to be seen mingled with the marrow-leucocytes a number of corpuscles somewhat smaller in size, nucleated, and at least some of them amœboid, but of a reddish tint (fig. 61, *e′*). These cells, which by mitotic division produce ***erythroblasts***, resemble the nucleated coloured corpuscles of the embryo.

They vary in size, most measuring about ·007 mm. (normoblasts), but some being considerably larger (megaloblasts), and others considerably smaller (microblasts). The red disks are formed from the erythroblasts by the nucleus disappearing and the coloured protoplasm becoming moulded into a discoid shape. At what time this formation of blood-corpuscles in the bone-marrow begins has not been ascertained, but after it has commenced it continues throughout the whole of life—the red marrow, especially that of the ribs, being especially active in this respect. In mammals the multiplication of nucleated coloured corpuscles appears to take place wholly within the tissue of the marrow external to the blood-vessels. It is uncertain to what extent the capillary vessels of the marrow are limited by a complete endothelium (see next page), but in any case the formed erythroblasts seem to readily pass into the blood stream. In birds the formation of erythroblasts is confined to the large blood-channels of the marrow, and the transformation into erythrocytes occurs within these channels.

Many of the erythroblasts in the marrow are in process of mitotic division. Others are seen with the nucleus in a more or less atrophied condition: from this it is inferred that the transformation into a discoid blood-corpuscle is accompanied by the disappearance of the nucleus. Whether this eventually becomes extruded or simply undergoes complete atrophy is uncertain. The marrow also contains a number of very large cells, the *giant-cells* or *myeloplaxes* of Robin (fig. 61, *meg*; fig. 62). Giant-cells are especially numerous wherever bone is becoming absorbed, but are not confined to such situations, being normal constituents of adult red marrow. Sometimes they possess several nuclei, but most—the so-called *megakaryocytes*—contain but one large nucleus, which has usually an annular form, is lobulated, and contains a number of nucleoli. They are also characterised by possessing a number of centrioles grouped together near the centre. Giant-cells are found in all blood-forming organs, *e.g.* the lymph-glands and spleen of young animals, as well as in bone-marrow. Under pathological conditions they may occur in many other tissues. It has been suggested by Wright that they give origin to the blood-platelets.

Cells are sometimes found in marrow containing blood-corpuscles in various stages of transformation into pigment, similar to those which occur in the spleen-pulp.

The marrow is very vascular, the capillaries and veins being large and thin-walled; indeed, according to some authorities, the walls of the capillaries are imperfect, so that there is an open communication between them and the interstices of the tissue, and in this way it is supposed that the coloured blood-disks which are produced from the erythroblasts of the marrow may get into the circulation. There is not, however, an interstitial circulation of blood in the marrow such as is found in the spleen, nor does injection material such as carmine gelatine pass into the interspaces of the tissue; but it remains confined to the vessels, so that the existence of an open communication is improbable.

Development of white corpuscles.—Leucocytes occur originally as free mesenchyme cells, and are believed to find their way into the vessels from the circumjacent mesoderm. Some authors state that they are produced by division of the primitive blood-cells, some of these forming primitive lymphocytes, others primitive erythroblasts. According to most authors they do not occur within the first-formed blood-vessels of the embryo. They are not seen within the vasoformative cells. In later stages of fœtal life and during the whole of post-embryonic life they become formed in the bone-marrow, as well as in lymph-glands, in the Malpighian corpuscles of the spleen, and in other organs composed of lymphoid tissue; they pass from these directly into the lymphatics and into the blood.

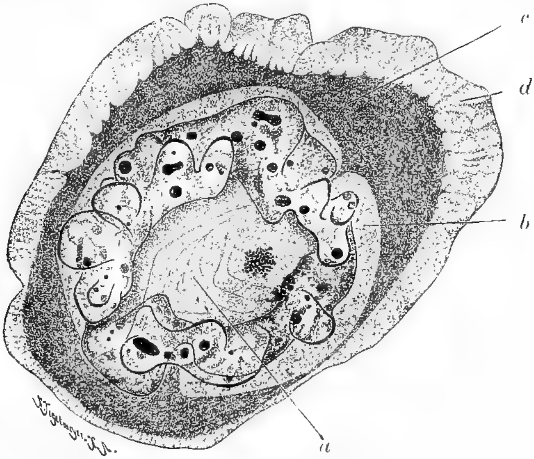

FIG. 62.—GIANT-CELL OF MARROW (RABBIT) WITH ANNULAR NUCLEUS AND NUMEROUS CENTRIOLES. (M. Heidenhain.)
a, *b*, *c*, *d*, zones in protoplasm.

It is regarded as probable, but has not been ascertained with certainty, that the macrocytes are formed by enlargement of the lymphocytes. Some authors believe that the lymphocytes give origin to all the various kinds of leucocytes. Others, on the other hand, consider that the polymorphocytes and the coarsely granular oxyphil leucocytes are formed within the bone-marrow, which contains cells of similar character. Leucocytes with well-marked basiphil granules are also met with in bone-marrow; these sometimes, under abnormal conditions, pass in large numbers into the blood, which normally does not contain any such cells in the adult human subject.

LESSON IV.

ACTION OF REAGENTS UPON THE HUMAN BLOOD-CORPUSCLES.

1. Make a preparation of human blood, and apply a small drop of water at one edge of the cover-glass. Examine at a place where the two fluids are becoming mixed. Notice particularly the first effect of water upon both red and white corpuscles, as well as the ultimate action.

Sketch both kinds of corpuscles under the action of water.

2. Repeat on another preparation, using very dilute alkali (0·2 per cent. caustic potash) instead of water. Notice the complete solution first of the white and then of the coloured corpuscles as the alkali reaches them.

3. Repeat on another preparation, using dilute acetic acid (1 per cent.). Observe that the effect of the acid upon the coloured corpuscles is similar to that of water, but that it has a different action upon the colourless corpuscles.

Sketch two or three of the latter after the action is completed.

4. Make a preparation of blood mixed with salt solution, as in Lesson II. 2, and investigate the action of tannic acid (1 part tannic acid to 100 of distilled water) in the same way.

Sketch two or three coloured corpuscles after the action is complete.

5. Examine blood-crystals of rat, guinea-pig, and squirrel. They can be obtained from these animals by merely mixing blood with a little water, and can be preserved in glycerine or Farrant, or, after dehydration, in dammar.

6. Prepare hæmin by heating a dry smear of blood on a slide with glacial acetic acid. It is not necessary to add salt since this is present in the blood. The crystals of hæmin are permanent.

Structure of erythrocytes.—The action of reagents upon the human red blood-corpuscles shows that, although to all appearance homogeneous, they in reality consist of an external envelope of colourless matter which forms a thin film enclosing the dissolved coloured material or *hæmoglobin*. Thus, when water reaches the corpuscle, it passes through the film and swells the corpuscle, causing it to become globular; eventually the film is burst, or is sufficiently distended to allow the solution of hæmoglobin to escape through its pores, the colourless envelope (the so-called *stroma*) being left (fig. 63, *a* to *e*). The addition of hyperisotonic solution of salt, on the other hand, by increasing the density of the fluid in which the corpuscles float, causes diffusion of water out of the corpuscle, and consequent shrinking and corrugation of the surface, a crenated or thornapple form (fig. 63, *f*) being produced. The same

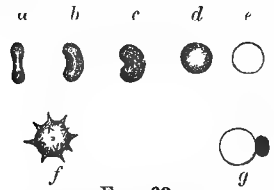

Fig. 63.

a-*e*, successive effects of water upon a red corpuscle; *f*, effect of solution of salt; *g*, effect of tannic acid.

change is brought about by evaporation of water, if the blood is exposed to air. The separation of hæmoglobin from the corpuscle can be effected not only by water, but also by dilute acids, by the action of heat (60° C.), the freezing and thawing of blood, the action of ether or chloroform, and the passage of electric shocks. Bile and dilute alkalies rapidly cause the red corpuscles to become spherical and then almost instantly effect their complete solution (hæmolysis). The mixing of blood from one species of animal with the blood or serum of animals of other species has a similar effect. In this case the hæmolytic action is exerted by a constituent (hæmolysin) of the foreign blood, which is special for each species and against which the "host" can render itself immune if, prior to any large quantity of the foreign blood or serum being injected, successive small injections be made; an "anti-hæmolysin" being gradually produced. This fact is not only of interest as bearing upon the general doctrine of immunity, but can also serve to detect the source of a given sample of blood.

Tannic acid produces a peculiar effect upon the red corpuscle (fig. 63, *g*); the hæmoglobin is discharged from the corpuscle, but is immediately altered and precipitated, remaining adherent to the envelope in the form of a round or irregular globule of a brownish tinge (hæmatin ?).

Some of these reactions occur by a process of osmosis as in the case of water, but in others a solution of the envelope of the corpuscle is produced by the reagent, or the envelope is altered and rendered more porous so that the hæmoglobin is able to escape. The film or envelope is probably composed of protoplasm, containing, as is always the case, besides nucleo-proteids, lipoids, such as lecithin and cholesterol; substances which possess many of the physical properties of fats. If we assume that they are accumulated so as to form an external film to the corpuscle, the running of the red disks into rouleaux can readily be explained, since it has been shown by Norris that disks of any material, *e.g.*, cork, suspended in a fluid, tend in the same way to adhere in rouleaux, provided their surfaces are covered with a layer which is not wetted by the fluid. The fact that no rent is ever seen in the envelopes of the red corpuscles even when they appear to have burst may also be explained on the same hypothesis, for, if the external film is of a fatty nature, any rent in it would tend immediately to close up again when the opposed edges come into contact. It was further shown by Norris that droplets of fluid encompassed by a lipoid film have a tendency to assume a flattened shape; this suggests an explanation of the flattened form of the erythrocyte.

The envelope of the erythrocyte was termed the *stroma* by Rollett, a name which rests upon a false conception of the structure of the corpuscle. In adopting the name, he supposed that the corpuscle is formed of a homogeneous solid or semi-solid protein material, in the pores of which the hæmoglobin is contained. But there is no reasonable foundation for this belief, which has nothing in its favour and wholly fails to explain the well-known osmotic phenomena of the corpuscle; whereas the supposition that the corpuscle consists of an envelope enclosing coloured fluid is in accordance with all the known facts regarding the action of reagents upon these bodies. It is true that in the fresh mammalian corpuscle the envelope is too delicate to be actually observed in the optical section of the corpuscle, but in the blood-corpuscles of Amphibia it can be distinctly seen, and with any slight increase in density of the plasma it tends to become wrinkled and creases are then plainly visible in it. In these corpuscles also the nucleus becomes readily displaced, in freshly drawn blood, from its position in the centre of the corpuscle and may lie quite at the side (fig. 77); this is a clear indication of the fluid nature of the contents of the corpuscle, and by analogy we may fairly assume a similar constitution for the mammalian corpuscle. Lastly, it is possible to show the envelope of the red corpuscles of mammalia by staining with methyl violet and other dyes.

Blood-crystals—Hæmoglobin.—In the blood of many animals (fig. 64), crystals of hæmoglobin readily form after this substance is extracted from the red corpuscles although it never crystallises within them, being kept in solution by some means which is not fully understood. The crystals are rhombic prisms in man and most animals, but tetrahedra in the guinea-pig, and hexagonal plates in the squirrel. In many animals they at once appear on shaking up the blood with chloroform or ether, or even on the mere addition of water, with or without subsequent evaporation, but in others and in man they are more difficult to obtain.

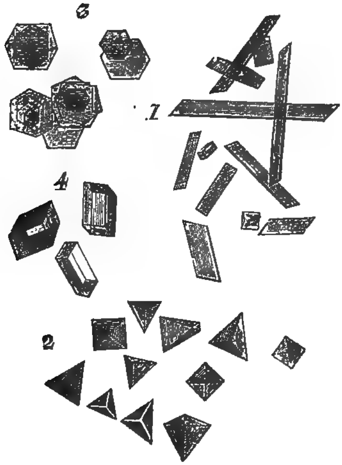

Fig. 64.—Blood crystals, magnified.
1, from human blood; 2, from the guinea-pig; 3, squirrel; 4, hamster.

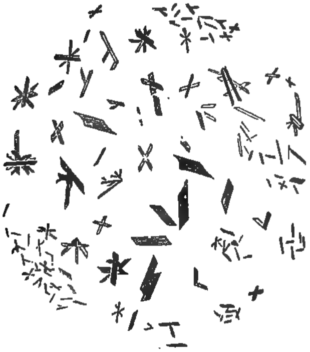

Fig. 65.—Hæmin crystals, magnified. (Preyer.)

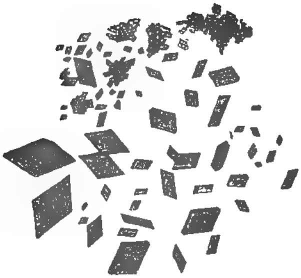

Fig. 66.—Hæmatoidin crystals. (Frey.)

Hæmin.—This name was applied by Teichmann to the minute dark-brown rhombic crystals of hydrochlorate of hæmatin (fig. 65), which are formed when dried blood from any source whatever is heated with glacial acetic acid.

Hæmatoidin.—This occurs in the form of brownish-yellow crystals (fig. 66). It is found in old blood extravasations and in other places where blood-corpuscles are undergoing disintegration within the tissues.

Action of reagents on leucocytes.—The structure of the colourless corpuscles is also brought out by the action of some of the reagents above noticed. As the water reaches them their amœboid movements cease; they become swollen out into a globular form by imbibition of fluid (fig. 67, 1), and the granules within the protoplasm take on an active Brownian motion. The nucleus also becomes clear and globular, and is more conspicuous than before. With the further action of water, the corpuscle is disintegrated and the granules are set free.

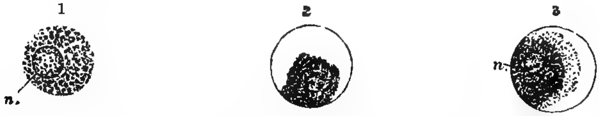

FIG. 67.

1, first effect of the action of water upon a white blood-corpuscle; 2, 3, white corpuscles treated with dilute acetic acid; *n*, nucleus.

Acids have an entirely different action upon the white corpuscles. Their nuclei become shrunken and very distinct (fig. 67, 2 and 3), and a granular precipitate is formed in the protoplasm around the nucleus. At the same time, a part of the protoplasm generally swells out so as to form a clear bleb-like expansion (an appearance which also often accompanies the death of the corpuscle from other causes). Caustic alkalies, even as dilute as two parts per 1,000 of saline, rapidly cause complete destruction and solution of the white corpuscles.

LESSON V

THE BLOOD-CORPUSCLES OF AMPHIBIA.

1. Obtain a drop of frog's, toad's or newt's blood, and mix it with a very small quantity of Ringer's solution upon a slide. Examine with the high power. Notice the shape of the coloured corpuscles both when seen flat and edgeways, and the nucleus within each.

Measure ten corpuscles (long and short diameters), and from the results obtain the average dimensions of a corpuscle.

Notice also the colourless corpuscles, smaller than the red, but larger than the pale corpuscles of human blood, although otherwise generally resembling these. Spindle-shaped blood-platelets may also be seen.

Sketch two or three red corpuscles and as many white.

Be careful not to mistake the rounded liberated nuclei of crushed red corpuscles for pale corpuscles.

Enormous cells and nuclei belonging to the cutaneous glands as well as the granular secretion of those glands may be present in this preparation if it is obtained from the newt's tail.

2. Apply a drop of water to the edge of the cover-glass of the above preparation and notice its action upon the corpuscles.

Sketch two or three corpuscles altered by the action of the water.

3. Mount another drop of blood, and apply dilute acetic acid (1 per cent.) instead of water at the edge of the cover-glass. Make sketches showing the effect of the acid upon both red and white corpuscles.

4. Examine the corpuscles of newt's blood which has been allowed to flow into boric acid solution (2 per cent.). Notice the effect produced upon the coloured corpuscles. Sketch one or two.

5. Mount drops of glycerine-jelly containing (*a*) frog's or newt's blood and (*b*) bird's blood, previously fixed by Flemming's solution and stained with picro-carmine.

6. Make film preparations of amphibian and bird's blood as described on p. 31, § 5, for human blood.

The **coloured blood-corpuscles of Amphibia** (figs. 68, 69), as well as of nearly all vertebrates below mammals, are biconvex elliptical disks, considerably larger than the biconcave circular disks of mammals.[1] In addition to the coloured body of the corpuscle, which consists, as in mammals, of hæmoglobin enclosed within an envelope, there is a colourless *nucleus*, also

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[1] The following are the dimensions in parts of a millimeter of the coloured corpuscles of some oviparous vertebrates :—

	Long Diameter.	Short Diameter.
Pigeon	0·0147	0·0065
Frog	0·0223	0·0157
Newt	0·0293	0·0195
Proteus	0·0580	0·0350
Amphiuma	0·0770	0·0460

of an elliptical shape, but easily becoming globular, especially if liberated by any means from the corpuscle. The nucleus resembles that of other cells in structure, being bounded by a membrane and having a network of chromatin. It is not very distinct in the unaltered corpuscle, but is brought clearly into view by the action of reagents, especially acids. The action of reagents upon the red corpuscle of Amphibia is otherwise similar to that upon the mammalian corpuscle, water and acetic acid causing it to swell into a globular form and then to become decolorised; solution of salt causing

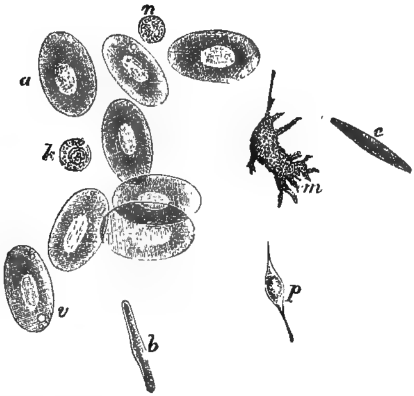

FIG. 68.—BLOOD-CORPUSCLES OF FROG. (Ranvier.)

a, seen on the flat; *b*, in optical section; *c*, in profile; *v*, a corpuscle with apparent vacuoles (probably parasitic organisms which are common in frog's blood-corpuscles); *m*, an amœboid leucocyte; *n*, nucleus of an erythrocyte, set free and contracted to the spherical form; *k*, a lymphocyte; *p*, a blood-platelet.

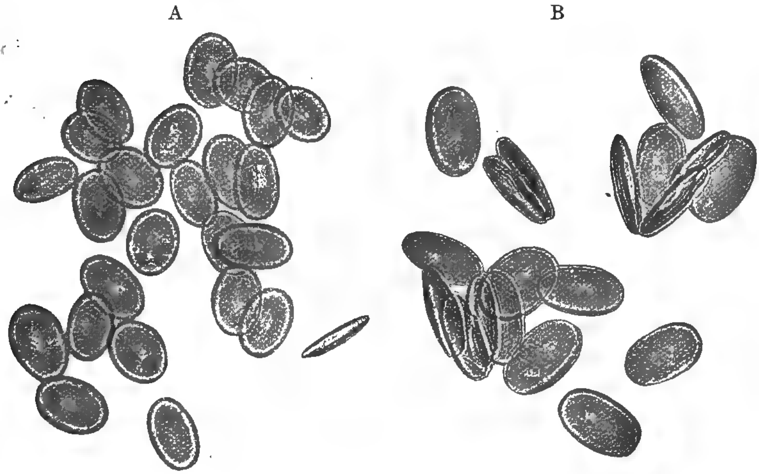

FIG. 69.—AMPHIBIAN ERYTHROCYTES. Photographs. Magnified 450 diameters.

A, from the frog. *B*, from the toad.

wrinkling of the envelope, and so on. As a first effect, water and certain other fluids may cause the hæmoglobin to retire from the envelope at the points where the fluid is passing through the membrane: a stellate appearance is thereby often produced. Boric acid causes the hæmoglobin of the newt's corpuscle to become partially or wholly collected around the nucleus, which may then be extruded from the corpuscle.

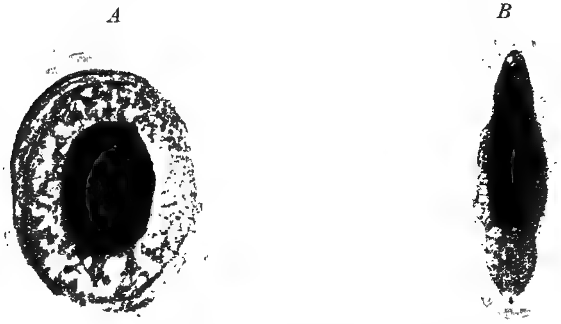

FIG. 70.—ERYTHROCYTES OF LEPIDOSIREN LARVA, FIXED WITH FLEMMING'S SOLUTION AND STAINED WITH IRON-HÆMATOXYLIN. (T. H. Bryce.)

A, as seen on the flat; *B*, in section. In *A* the fibrils around the edge are visible as fine lines parallel to the margin of the corpuscle. In *B* their sections are seen as fine points just within the thinnest part of the edge.

Immediately within the envelope, at the periphery of the amphibian erythrocyte, is a band of fine fibrils which are stained by gentian violet (Meves). As Bryce has shown, they can also be seen cut across in sections of the corpuscles, and may be stained with iron-hæmatoxylin (fig. 70).

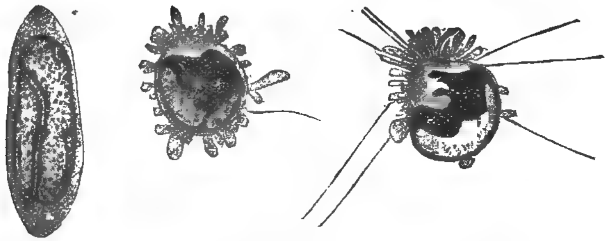

FIG. 71.—A BLOOD-PLATELET OF SALAMANDRA, AND THE CHANGES WHICH IT UNDERWENT IMMEDIATELY AFTER WITHDRAWAL OF THE BLOOD FROM THE VESSELS. (F. Meves.)

The colourless corpuscles of Amphibia, although larger, are very similar to those of mammals. Like them, they are either wholly pale and finely granular, or enclose a number of very distinct granules of similar nature to those met with in mammals. These corpuscles vary much in size and in the activity of their amœboid movements: those which have a multilobular nucleus (fig. 75) are usually the most active. Reagents have the same effect upon the

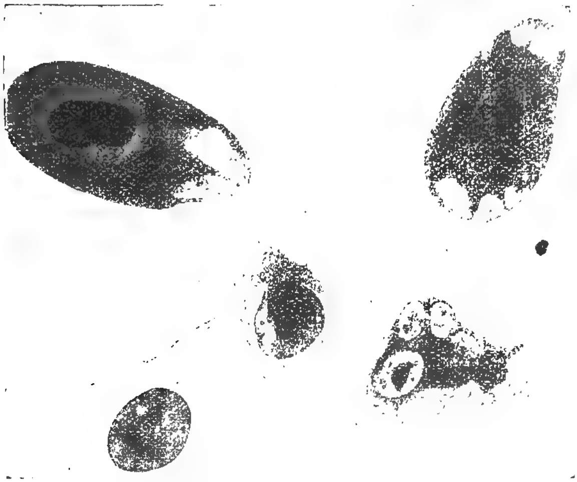

FIG. 72.—A BLOOD-PLATELET OF SALAMANDRA, SHOWING ITS IRREGULAR PROJECTIONS AND FIBRINOUS FILAMENTS RADIATING FROM IT AND ATTACHED TO ADJACENT BLOOD-CORPUSCLES. (F. Meves.)

Two erythrocytes, one free nucleus, and one polymorph leucocyte are included in the figure.

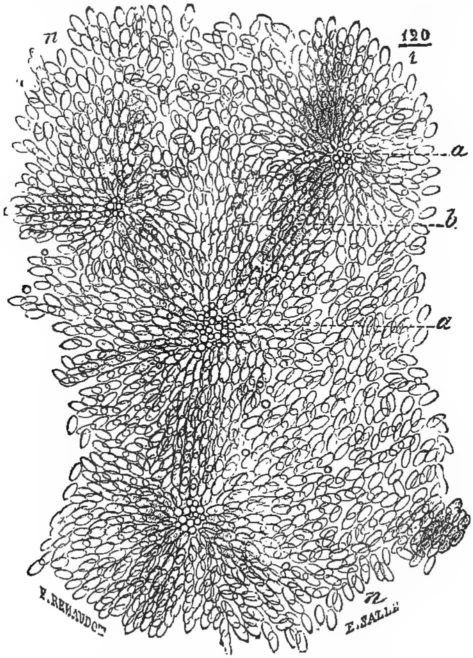

FIG. 73.—MICROSCOPIC PREPARATION OF FROG'S BLOOD SHOWING THE MANNER IN WHICH THE ERYTHROCYTES BECOME ARRANGED OWING TO THEIR FIXATION BY THE CONTRACTING THREADS FROM THE BLOOD-PLATELETS. (Raimer.)

a, position of groups of blood-platelets; *b*, erythrocytes along a line uniting two groups.

amphibian leucocytes as on those of mammals. The presence of glycogen may be demonstrated in them by its reaction with iodine solution (port-wine colour).

The **blood-platelets** (thrombocytes) in the frog are much fewer in number than in mammals. They are of a spindle shape (fig. 68, *p*). They contain a nucleus-like body, and like the blood-platelets of mammals they show rapid changes as soon as the blood is drawn. These changes are represented in the accompanying figures (figs. 71 and 72) from Meves. The elongated corpuscle first contracts and becomes more globular, its nucleus also changing similarly in shape. Irregular processes then begin to be protruded, and very soon fine threads are shot out radially in all directions. These become attached to those of other platelets, or to any solid object which may be in the vicinity of the platelet. The filaments, which appear to be of a fibrinous nature, and may possibly be threads of fibrin, then begin to retract and drag upon the objects which are entangled by them. In this manner a number of erythrocytes may be drawn together towards a common centre and assume a more or less radial arrangement (fig. 73). Probably similar changes occur in the blood-platelets of mammalian blood after it is drawn. It is believed that such entanglement of blood-platelets and other corpuscles may serve rapidly to plug small apertures in blood-vessels caused by injury, and thus serve to aid in arresting hæmorrhage.

LESSON VI.

THE AMŒBOID PHENOMENA OF THE COLOURLESS BLOOD-CORPUSCLES.

1. MAKE a preparation of blood from the finger in the usual way. Draw a brush just moistened with pure paraffin oil around the edge of the cover-glass to prevent evaporation. Avoid an excess of oil. Place the preparation upon a "warm stage," and heat this to about the temperature of the body (38° C.). Bring a white corpuscle under observation with the high power, and watch the changes of shape which it undergoes. To become convinced of these alterations in form, make a series of outline sketches of the same corpuscle at intervals of a minute.

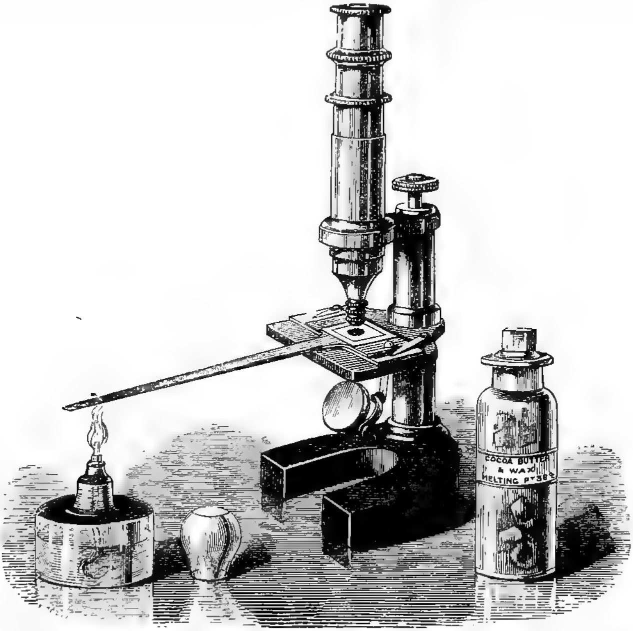

FIG. 74.—SIMPLE WARMING APPARATUS, COMPLETE, SHOWN IN OPERATION.

The simplest form of warm stage is a copper plate of about the size of an ordinary slide, perforated in the centre and with a long tongue of the same metal projecting from the middle of one edge (fig. 74). The copper plate rests upon the stage of the microscope, with a piece of asbestos or other non-conducting material between. The preparation is made upon an ordinary slide or on a long cover-glass, which is placed upon the warm stage and pressed into contact with it by the brass clips of the microscope. Heat is applied to the copper tongue by a small spirit-lamp flame, and a greater or less amount is conducted to the warm stage and the superjacent preparation according to the point to which the flame is applied. To ascertain that the right temperature is got and maintained, put two pieces of solid paraffin, one melting at 35° C. (95° F.) and another at 38° C. (100° F.), one on either side of the preparation. The temperature must be such that the first piece is melted and remains so whilst the second remains unmelted.[1]

2. Mount a drop of frog's or newt's blood diluted with an equal amount of salt solution, and examine it in the same manner upon the copper stage, at first cold, afterwards warm; the temperature must, however, be kept below 30° C. Observe the effect of warmth in accelerating the amœboid movements of the pale corpuscles. Sketch one at intervals of a minute (*a*) in the cold, (*b*) whilst warmed.

3. Take some yeast which has been mixed with salt solution, and mix a very little of the yeast and salt solution with a fresh drop of newt's blood, slightly oiling the edge of the cover-glass as before. Endeavour to observe the inception of the yeast-torulæ by the white corpuscles. Sketch one or two corpuscles which have ingested torulæ.

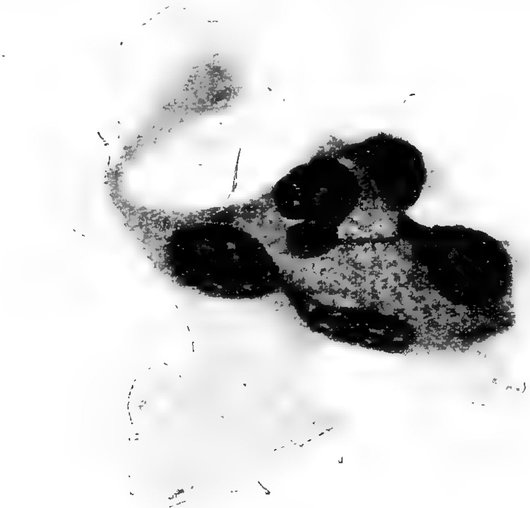

FIG. 75.—A POLYMORPH LEUCOCYTE OF TRITON FIXED BY STEAM IN AMŒBOID CONDITION AND STAINED WITH HÆMATOXYLIN. Untouched photograph. Magnified 1360 diameters.

Notice the homogeneous appearance of the protoplasm of the pseudopodia as compared with that of the body of the corpuscle. The nucleus is multilobed, the lobes being joined by threads of chromatin. Its reticular structure is well shown.

Particles of carbon or of vermilion may be used instead of yeast for this experiment.

4. At the beginning of the lesson collect a drop of newt's or frog's blood into a very fine capillary tube. After a few minutes it will be coagulated and the clot may then be blown out into a drop of salt solution on a slide and covered. Examine the edge of the clot to see white corpuscles emigrating from it.

5. To obtain a specimen with the white corpuscles fixed in amœboid condition, a preparation of newt's blood mixed with salt solution is made, and set aside for ten minutes. By this time the corpuscles will be freely amœboid, and may show well-marked pseudopodia. To fix them in this condition let a jet of steam from a tube attached to a boiling flask or kettle of water play for a second upon the cover-glass. The heat instantly kills the corpuscles, and they are fixed in the form they presented at the moment the steam was applied. They

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[1] For exact work, an apparatus somewhat more complex than the above is required. For description of such apparatus, see the author's *Course of Practical Histology.*

may now be stained by passing dilute hæmatoxylin[1] under the cover-glass, the stain being followed by dilute glycerine. When this has diffused through the preparation (it must not be drawn under by filter paper), the cover may be cemented and the preparation kept.

The **amœboid phenomena** which are exhibited by the protoplasm of the colourless blood-corpuscles consist of spontaneous changes of form, produced by the throwing out of processes or *pseudopodia* in various directions. When first thrown out the pseudopodia are quite clear; they appear to be composed only of the hyaloplasm which flows out in any direction in which the surface tension is for the moment diminished (see p. 7). If the corpuscle is stimulated, either mechanically, as by tapping the cover-glass, or electrically, the pseudopodia are retracted, the corpuscles becoming spherical. A change of form caused by the protrusion of the pseudopodia may, when active, be followed by changes in place or actual locomotion (migration) of the corpuscle. When a pseudopodium, or the external surface of the protoplasm, comes in contact with any foreign body, the protoplasm tends to flow round and enwrap it; if it is small, it is drawn into the corpuscle; particles thus ingested may be conveyed by the corpuscle in its movements from one place to another (fig. 78). This property plays an important part in many physiological and pathological processes; thus cells in the spleen resembling large leucocytes—the so-called *splenic cells*—take in blood-corpuscles, which become broken down within them; and pathogenic bacteria become taken into the protoplasm of certain leucocytes (on this account termed *phagocytes*), there to

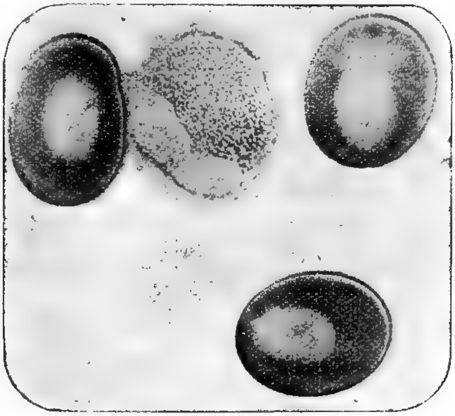

FIG. 76.—AN EOSINOPHIL LEUCOCYTE OF SALAMANDRA BEGINNING TO ADHERE TO AN ERYTHROCYTE. Perfectly fresh preparation without addition of fluid. Untouched photograph. Magnified 600 diameters.

Two other erythrocytes are included in the field. Notice that the nuclei in these have undergone a change of position within the corpuscle, showing that its contents must be completely fluid.

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[1] The water used for the dilution of hæmatoxylin solutions must always be distilled.

be destroyed (Metchnikoff). The phagocytic properties of the leucocytes become especially developed as the result of the action upon the bacteria of certain substances which are present to a variable extent in blood and are termed *opsonins* (Wright). They are also stimulated by all agents which act upon the lipoid substances, which form, it is believed, a delicate surface film over the protoplasm of all amœboid cells, and Hamburger, who makes this observation, points out that the beneficial action of certain medicinal remedies is probably due to the fact that they influence the leucocytes of the blood in this manner and tend to increase their phagocytic activity.

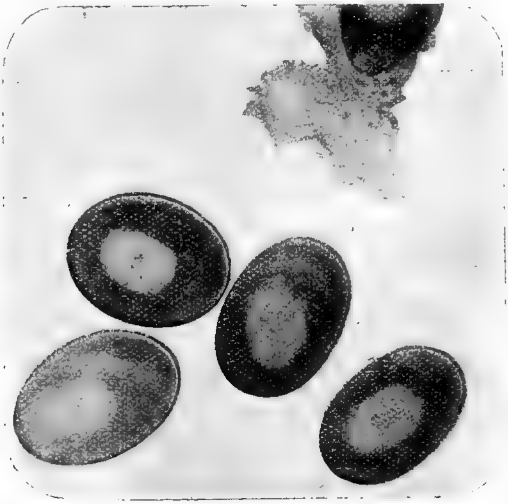

Fig. 77.—A highly amœboid phagocytic polymorph leucocyte of Salamandra, enveloping an erythrocyte (a portion only of this is included in the field). Untouched instantaneous photograph. Magnified 600 diameters. Four other erythrocytes are seen.

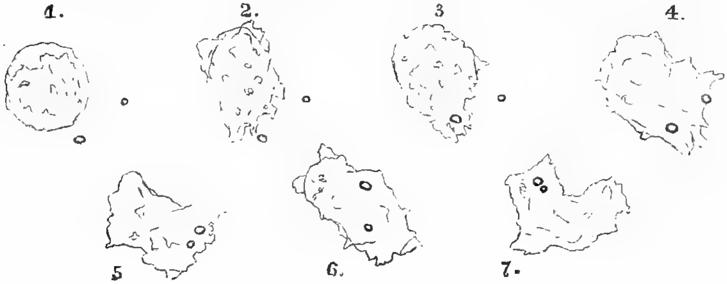

Fig. 78.—Changes of form of a white blood-corpuscle sketched at intervals of a few minutes, showing the inception of two small granules and the changes of position these underwent within the corpuscle.

It is probable that particles of organic matter which are taken up by the pale corpuscles may undergo some slow process of intracellular digestion within the protoplasm.

The migration of the colourless corpuscles from the blood-vessels into the surrounding tissues (which especially occurs in inflamed parts), or from a bloodclot into the surrounding serum, is due to their amœboid properties.

Conditions which are favourable to the amœboid activity of the white corpuscles are (1) the natural slightly alkaline medium, such as plasma, serum, or lymph, or faintly alkaline normal saline solution; (2) a certain temperature. In warm-blooded animals the phenomena cease below about 10° C. When gradually warmed the white corpuscles become more and more active up to a certain point, the maximum being a few degrees above the natural temperature of the blood. Above this point they become spheroidal and at a somewhat higher temperature their protoplasm is coagulated and killed. Acids at once kill the corpuscles and stop the movements. Narcotic gases and vapours, such as carbonic acid gas or chloroform vapour, also arrest the movement, but it recommences after a time if their action is not too prolonged.

Any increase of density of the medium produces a diminution of amœboid activity, whilst, on the other hand, a slight decrease in its density has the opposite effect.

Jolly found that if blood-plasma is preserved in sealed aseptic tubes, the white corpuscles may retain their vitality for as long a period as four and a half months.

LESSON VII.

EPITHELIUM AND SECRETING GLANDS.

1. MOUNT a drop of saliva and examine first with a low, afterwards with a high power. Observe the nucleated epithelium-cells, some single, and others still adhering together by overlapping edges. Measure three or four, and also their nuclei. Sketch one or two on the flat and edgeways. Notice the salivary corpuscles, which are migrated white blood-corpuscles swollen out by imbibition of water. The preparation may be stained by allowing a small drop of diluted hæmatoxylin to diffuse under the cover-glass : followed by an equally small drop of dilute glycerine (50 per cent.).[1]

2. Put a small shred of human epidermis into a drop of strong caustic potash solution (35 per cent.) for five minutes. Then break it up in water with needles, cover, and examine. Observe the now isolated swollen cells.

3. Study the arrangement of the cells in a section through some stratified epithelium, such as that of the mouth, skin, or cornea. Notice the changes in shape of the cells as they are traced towards the free surface. Measure the thickness of the epithelium. Count the number of layers of cells.

4. Make a preparation of the epithelium of the urinary bladder ; this may be slightly distended with bichromate of potassium saline (1 part bichromate to 800 of normal saline), and after an hour cut open and placed in more of the same solution. Take a small scraping of the lining epithelium on the point of a scalpel, and break it up by tapping it in a drop of *very dilute* hæmatoxylin on a slide. Put a small hair in the drop and cover. Add a *small drop* of dilute glycerine at one edge : allow this to diffuse under. Cement next day. Observe the large flat superficial cells, and the pear-shaped cells of the second layer. Sketch one of each kind. The cells will vary greatly in appearance according to the amount of distension of the organ.

5. Study the minute structure of epithelium-cells and their nuclei, both at rest and dividing, in sections of the skin of the newt's tail, or in shreds of peritoneum or of the amnion of the rat, or in sections of the salamander-tadpole. The preparation may, for this purpose, be stained either with hæmatoxylin or iron-hæmatoxylin, or with some aniline dye such as saffranin.
Sketch a cell with resting nucleus, and others with nuclei in different phases of karyokinesis.
The simple saccular skin-glands of Amphibia may also be seen and studied in sections of the newt's tail.

An **epithelium** is a tissue composed entirely of cells separated by a very small amount of intercellular substance (cement-substance) and generally arranged so as to form a membrane covering either an external or internal free surface.

The structure of epithelium-cells, and the changes which they undergo in cell-division, are well seen in the epidermis of the newt or of the salamander-tadpole (fig. 79); the cells and nuclei are much larger in these animals than in mammals.

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[1] In most cases where glycerine is mentioned Farrant's solution may be substituted (see Appendix).

Structure of epithelium-cells.—An epithelium-cell consists, like other cells, of *protoplasm* and *nucleus*. The protoplasm may either look granular, or it may have a reticulated appearance, or may exhibit fibrils. The nucleus is spherical or ovoid. Usually there is only one, but there may be two. The cell-substance is often modified in its chemical nature; its external layer may become hardened to form a sort of membrane, or the whole cell may become horny (keratinised); or there may be a separation of materials (granules)

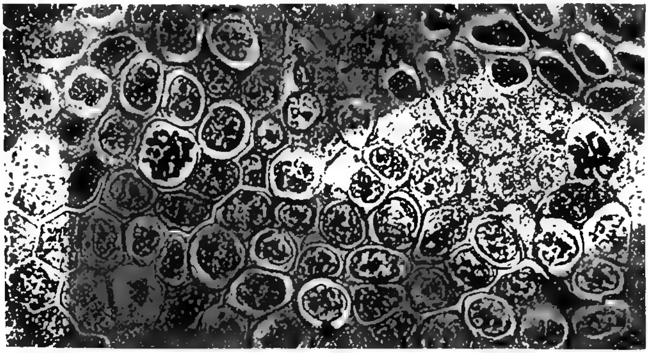

FIG. 79.—EPIDERMIS CELLS OF A LARVAL SALAMANDER. Magnified 400 diameters. Photograph.

Some of the cells are undergoing division. Intercellular channels are seen in parts. At one place the branches of a pigment-cell extend between the epithelium-cells.

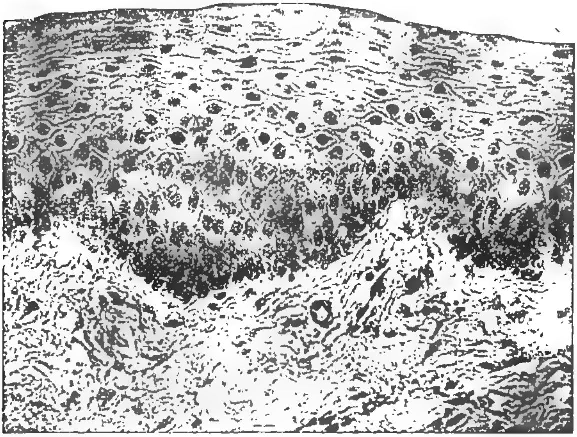

FIG. 80.—SECTION OF STRATIFIED EPITHELIUM FROM FAUCES OF RABBIT. Magnified 240 diameters. Photograph.

within the cell which are ultimately used by the organism, as in some secreting glands.

Classification of epithelia.—Epithelia are somewhat illogically classified partly according to the shape and arrangement of the cells, partly according to their function. Thus we speak of *scaly* or *pavement*, *cubical*, *columnar*, *glandular*, and *ciliated* epithelium. Most of these are *simple* epithelia, with the cells only one layer deep. If forming several superposed layers, the epithelium is said to be *stratified*, and then the shape of the cells differs in the different layers. Where there are only three or four layers in a stratified epithelium, it is termed *transitional*. A classification according to the function of the epithelium may also conveniently be adopted. We should then include under the term *protective epithelia*, the pavement, stratified and transitional varieties; under the term *secreting epithelia*, the cubical, columnar[1] and glandular epithelia (some of the pavement epithelia would come also under this head); while the *ciliated epithelia* would form a separate division, as in the classification above given.

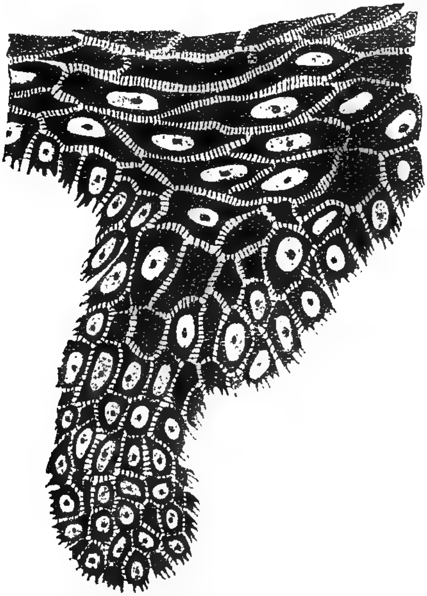

FIG. 81.—SECTION OF EPIDERMIS OF CAT'S FOOT SHOWING INTERCELLULAR CHANNELS, WITH BRIDGING FIBRILS. (Kolossow.)

Stratified epithelium (fig. 80) covers the anterior surface of the cornea, lines the mouth, pharnyx (lower part), gullet, anal canal and part of the urethra, and forms the epidermis which covers the skin. The vocal cords are covered by stratified epithelium. In the female it also lines the vagina and covers the os uteri. The cells nearest the surface are always flattened and scale-like, whereas the deeper cells are polyhedral, and those of the deepest layer somewhat columnar in shape. Moreover, the deep cells are soft and protoplasmic, and are separated from one another by a system of intercellular channels, which are bridged across by numerous fibrils passing from cell to cell (figs. 81, 82); giving the cells, when separated, the appearance of being beset with short spines (*prickle-cells*). These "bridging fibrils" are not peculiar to stratified epithelium, but occur in many tissues.

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[1] The columnar epithelium of the intestine is concerned as much with absorption as with secretion, but absorption may be regarded as a kind of reversed secretion.

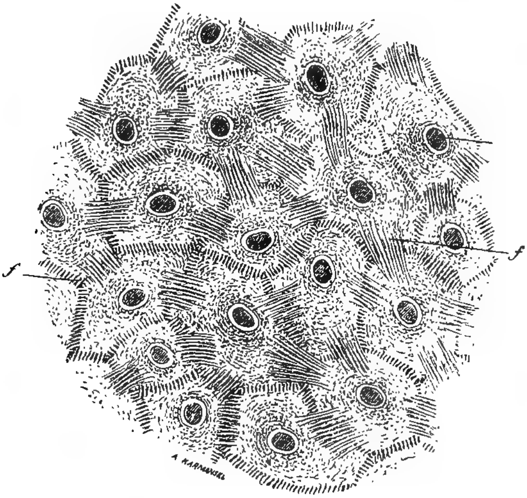

FIG. 82.—SECTION THROUGH THE DEEPER LAYERS OF A STRATIFIED EPITHELIUM, SHOWING FIBRILS, *f*, PASSING FROM CELL TO CELL ACROSS THE INTERCELLULAR SPACES. (Ranvier.)

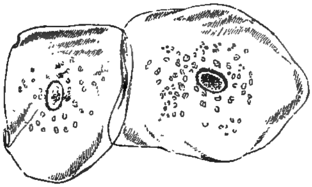

FIG. 83.—EPITHELIUM-SCALES FROM THE INSIDE OF THE MOUTH. (Sharpey.) Magnified 260 diameters.

The deeper cells multiply by karyokinesis. The newly formed cells tend as they enlarge to push those superficial to them nearer to the surface, from which they are eventually thrown off. As they approach the surface they become keratinised, and in the case of the epidermis entirely lose their cellular appearance, which can, however, be in a measure restored by the action of alkalies (§ 2). The cast-off superficial cells of the stratified epithelium of the mouth, which are seen in abundance in the saliva (§ 1), are less altered than those of the epidermis, and the remains of a nucleus is still visible in them (fig. 83).

The stratified epithelium of the human skin (epidermis) shows many peculiarities; these will be considered when the skin is treated of.

Transitional epithelium is a stratified epithelium consisting of only three or four layers of cells. It occurs in the urinary bladder, the ureter, and the pelvis of the kidney. The superficial cells (fig. 84, *a*) are large and flattened; they often have two nuclei. Their free surface is covered with a cuticular stratum, and on their under surface they exhibit depressions, into which fit the larger ends of pyriform cells, which form the next layer

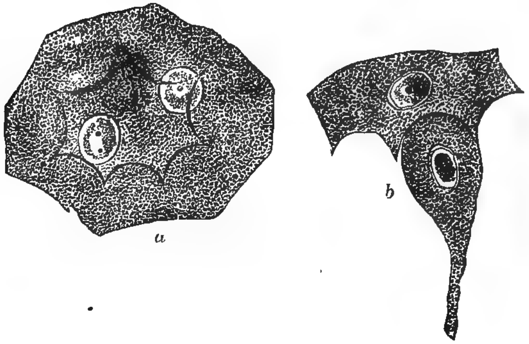

FIG. 84. -EPITHELIAL CELLS FROM THE BLADDER OF THE RABBIT. (Klein.) Magnified 500 diameters.

a, large flattened cell from the superficial layer, with two nuclei and with strongly marked ridges and intervening depressions on its under surface; *b*, pear-shaped cell of the second layer adapted to a depression on one of the superficial cells.

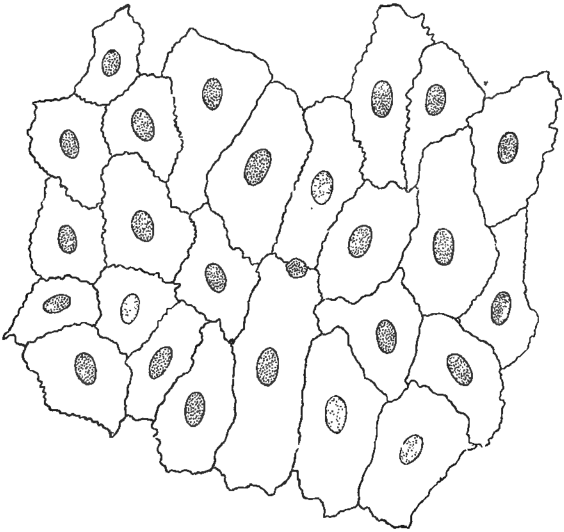

FIG. 85.—PAVEMENT EPITHELIUM OR ENDOTHELIUM OF A SEROUS MEMBRANE NITRATE OF SILVER PREPARATION. CARMINE STAINING OF NUCLEI.

(fig. 84, *b*). Between the tapered ends of the pyriform cells one or two layers of smaller polyhedral cells are found. The epithelium seems to be renewed by mitotic division of these deeper cells. It is possible that the superficial cells also multiply; it is stated that the division of their nuclei is amitotic (see fig. 19, p. 12).

Simple scaly or **pavement epithelium** is found in the saccules of the lungs, in the ducts of the mammary glands, in the kidney (in the tubes of Henle, lining the capsules of the Malpighian bodies, and covering the glomeruli), and also lining the cavities of serous membranes (fig. 85), and the interior of the heart, blood-vessels, and lymphatics. When occurring on internal surfaces, such as those of the serous membranes, blood-vessels, and lymphatics, it is spoken of as **endothelium** or (sometimes) **mesothelium.** Kolossow showed that the cells of a serous epithelium are provided with a striated border consisting of what appears to be a fine pile of closely set hairs on their free surface, somewhat like that which is found on columnar cells. These hairlets rest on a thin homogeneous border. The latter appears to be a common feature of endothelium for it also occurs in the endothelium of the blood-vessels, but the pile of hairs is only found in the endothelia of serous membranes, at least in mammals. Kolossow's statements have been confirmed by several other observers.

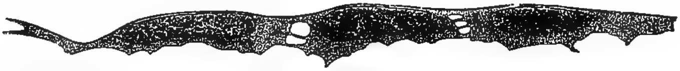

FIG. 86.—ENDOTHELIUM-CELLS OF SEROUS MEMBRANE SEEN IN PROFILE VIEW, SHOWING PROTOPLASMIC BRIDGES STRETCHING ACROSS THE INTERCELLULAR SPACES. (M. Heidenhain.)

In some amphibia cilia have been found on parts of the peritoneal epithelium (Klein).

GLANDULAR EPITHELIUM AND SECRETING GLANDS.

Glandular epithelium is the essential tissue of all the organs which are known as secreting glands. Glands are of two chief kinds. Those which are best known and which are termed *secreting glands proper* are furnished with a duct which ramifies in all parts of the gland and by means of which the products of the secretory activity of the gland-cells are brought to a free surface. Such glands have been developed as involutions of the surface upon which they open, and their epithelium is continuous with that of this surface, and is in some cases, especially where the surface upon which the gland opens is covered with columnar epithelium, of a similar character to the epithelium covering the surface. In other cases it is different in character from the epithelium of the surface, becoming altered as we trace the duct back into the recesses or *alveoli* of the gland, and it is in these that the characteristic glandular cells, which are generally polyhedral in shape, are found. Every such involution or ingrowth of epithelium to form a gland is, when first formed

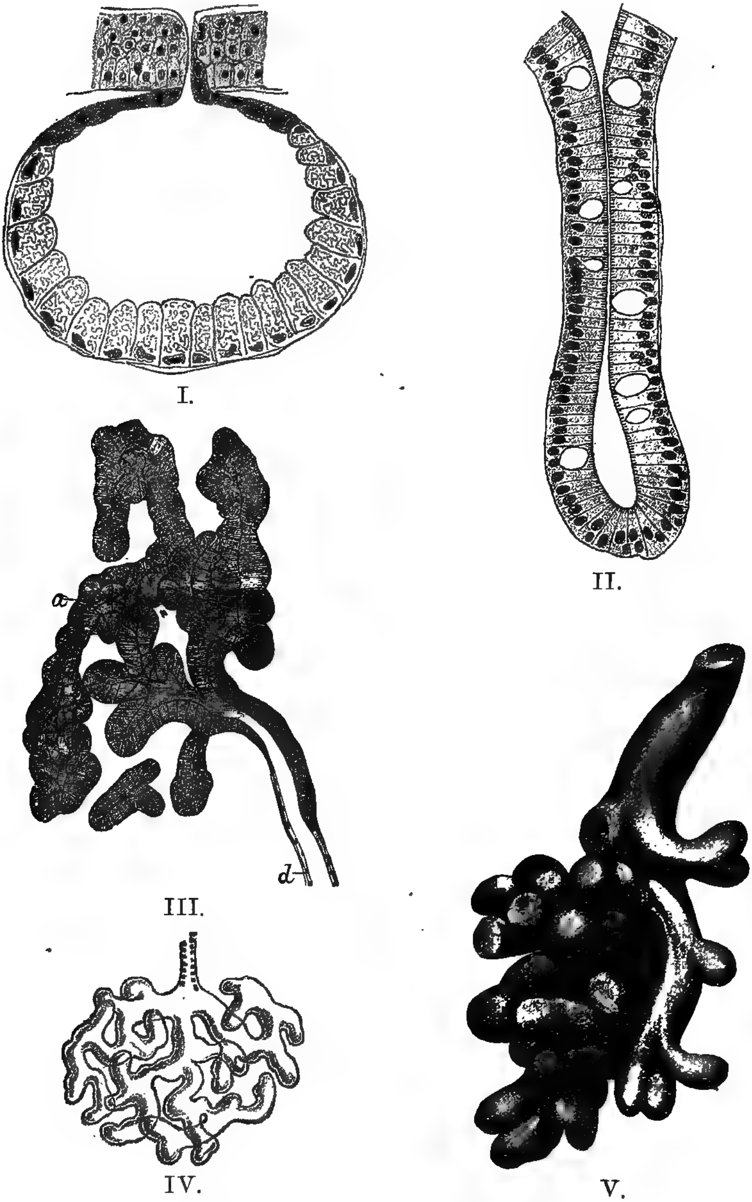

FIG. 87.—VARIOUS KINDS OF GLANDS.

I. Simple saccular gland from amphibian skin (Flemming). II. Simple tubular gland from intestine (Flemming). III. A small racemose gland with a single duct, *d*, into which a number of irregularly tubular acini, *a*, open (Klein). IV. Part of a tubulo-racemose gland with the acini unravelled (Flemming). V. Wax model of a small tubulo-racemose gland from the epiglottis (Maziarski).

of a simple character, shaped either like a flask or test-tube and filled with a solid mass of cells, but it presently becomes hollowed out, some of the cells being left as a lining to the connective-tissue membrane which bounds the involution. The gland may remain simple and unbranched (*simple saccular* and *simple tubular glands*, fig. 87, I. and II.), or it may branch again and again until a complicated structure, in some cases small, in others of considerable size, is produced (*compound tubular* and *compound saccular* (or *racemose glands*) (fig. 87, III., IV., V.), instances of which are furnished by the kidneys and salivary glands respectively). The cells which furnish the secretion of the gland and which line the secreting parts of the tubules of a tubular gland, or the alveolar enlargements (acini) at the ends of the ducts of a racemose gland, are often partly or wholly filled with granules in the intervals of secretory activity; these granules become discharged or dissolved and pass into the secretion during activity. Secreting glands are always abundantly supplied with blood-vessels and generally also with nerves. The blood-vessels are brought to the alveoli in the connective tissue which holds together the acini and groups of acini (lobules) of the gland; the nerves are supplied partly to the blood-vessels and partly to the secreting epithelium cells.

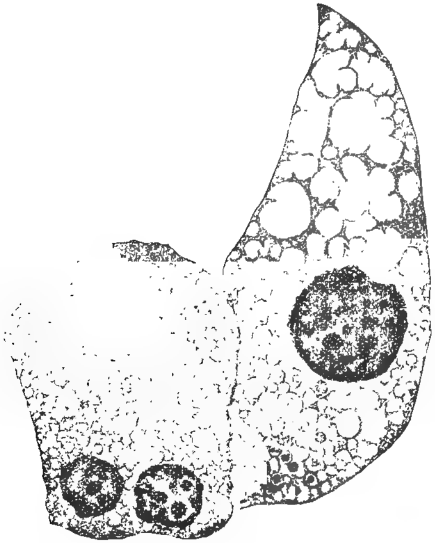

FIG. 88.—TWO CELLS FROM A CUTANEOUS GLAND OF SALAMANDER-LARVA, SHOWING THE SECRETION GRANULES. (Gurwitsch.)

The left-hand cell, which has two nuclei, is filled with granules. In the right-hand cell the granules are becoming swollen and dissolved.

The liver differs from all other secreting glands in being composed of solid masses of cells (hepatic lobules) instead of tubular acini lined by epithelium. It exhibits also other important differences in the nature of its blood-supply and the relation between the blood and the liver-cells.

The other kind of secreting glands, known as the *internally secreting* or *endocrine glands*, are not furnished with ducts and are usually classed with the spleen and lymphoid structures as *ductless glands*. But the endocrine glands are, like the externally secreting organs, composed of epithelial cells, sometimes grouped in solid masses (as in the suprarenal), in other cases disposed around hollow vesicles (thyroid) which become filled with the material of the secretion. Since there is no duct in these glands the secretion is carried into the blood either directly by the blood-vessels of the gland or indirectly through the lymphatics.

The detailed study of the glands and of other epithelial structures may be reserved until the organs in which they occur are described, but columnar and ciliated epithelia will be dealt with in the next lesson.

The *hairs* and *nails* and the *enamel* of the teeth are modified epithelial tissues. They will be described with the skin and with the structures connected with the mouth.

LESSON VIII.

COLUMNAR AND CILIATED EPITHELIUM: ACTION OF CILIA.

1. **Break** up in dilute glycerine a shred of epithelium from a minute piece of the mucous membrane of intestine (frog) that has been treated with 1 per cent. osmic acid for some hours, and has subsequently macerated in water for a few days. The cells easily separate on tapping the cover-glass. Measure and sketch one or two cells.

The cover-glass may be at once fixed by gold size.

2. Prepare ciliated epithelium from a trachea that has been treated with osmic acid like the last preparation, or that has macerated in chromic acid solution (1 to 2000 Ringer) for a few days. Measure in one or two of the cells (*a*) the length of the cell, (*b*) the length of the cilia, (*c*) the size of the nucleus. Sketch two or three cells.

3. Mount in sea-water one or two bars of the gill of the marine mussel (fig. 89). Study the action of the large cilia. Now place the preparation upon the copper warm stage (see Lesson VI.) and observe the effect of gently raising the temperature.

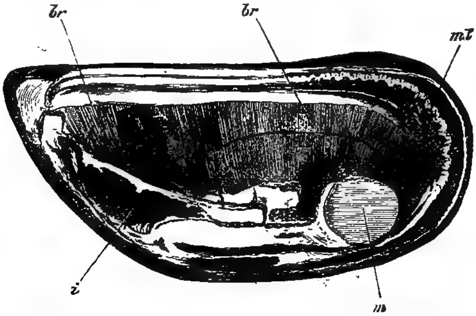

Fig. 89.—Valve of mussel (Mytilus edulis) showing *br*, *br*, the expanded gills or branchiæ, which, owing to the little bars of which they are composed, present a striated aspect.

ml, mantle; *m*, cut adductor muscle; *i*, mass of viscera; the dark projection just above is the foot.

Put this preparation aside, until the end of the lesson, by which time many of the cilia will have become languid. When this is the case pass a drop of dilute potash solution (1 part KHO to 1000 of sea-water) under the cover-glass and observe the effect.

4. Cement with sealing-wax a piece of small glass tubing to a slide so that one end of the tube comes nearly to the centre of the slide. To do this effectually the slide must be heated and some sealing-wax melted on to it and allowed to cool. The glass tube is then made hot and applied to the slide, embedding itself as it does so in the sealing-wax. Apply a ring of modelling wax (half an inch in diameter and rising above the glass tube) so as to include the end of the tube. Make a deep notch or a hole in the ring opposite the tube for the exit of CO_2 (see below). Place a drop of water within the ring (fig. 90).

Put a bar from the gill upon a cover-glass in the least possible quantity of sea-water; invert the cover-glass over the putty ring, and (with another slide) press it gently down. The preparation hangs in a *moist chamber* within which it can be studied through the cover-glass, and into which gases or vapours can be passed and their effects observed.

Pass CO_2 through the chamber, and after observing the effect replace it by air (fig. 91). Repeat with ether vapour and with chloroform vapour.

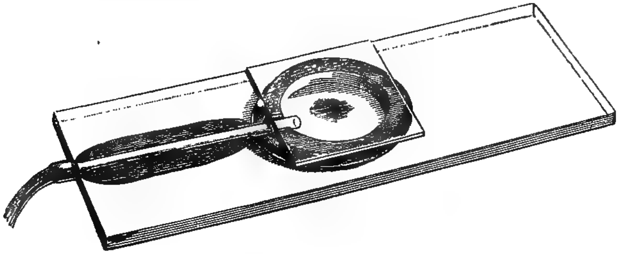

FIG. 90.—MOIST CHAMBER ADAPTED FOR PASSING A GAS OR VAPOUR TO A PREPARATION UNDER THE MICROSCOPE.

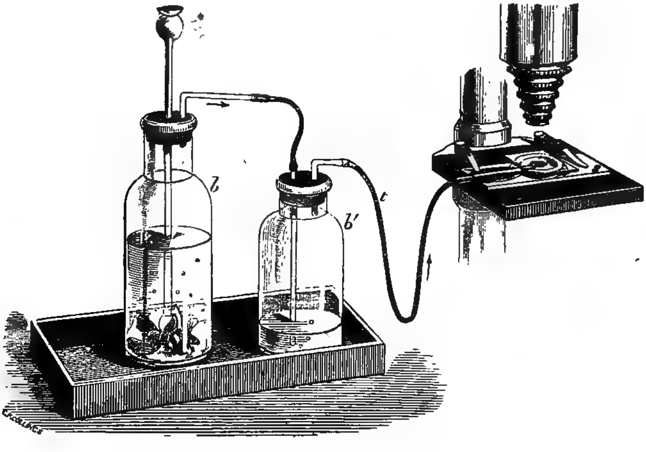

FIG. 91.—METHOD OF SUBJECTING A PREPARATION TO A STREAM OF CARBON DIOXIDE.

b, bottle containing marble and hydrochloric acid; *b′*, wash-bottle, connected by india-rubber tube, *t*, with the moist chamber, *s*.

Columnar epithelium and **ciliated epithelium** are for the most part found covering the inner surface of mucous membranes; which are membranes moistened by *mucus* and lining passages in communication with the exterior, such as the alimentary canal and the respiratory and generative passages. The cells of a columnar epithelium form a single layer, varying in thickness according to the length of the constituent cells, and when the cells of a columnar epithelium are short, the epithelium is spoken of as cubical, such as that which lines the vesicles of the thyroid gland (fig. 92). The cells of a columnar epithelium (fig. 93) are prismatic columns, which are set closely side by side, so that when seen from the surface a mosaic appearance is produced. They often taper somewhat towards their attached end, which is generally truncated, and set upon a basement membrane. Their free surface is covered by a thick striated border (figs. 93 to 97) which may sometimes become detached in teased preparations. The protoplasm of the cell is usually vacuolated or granular; between the

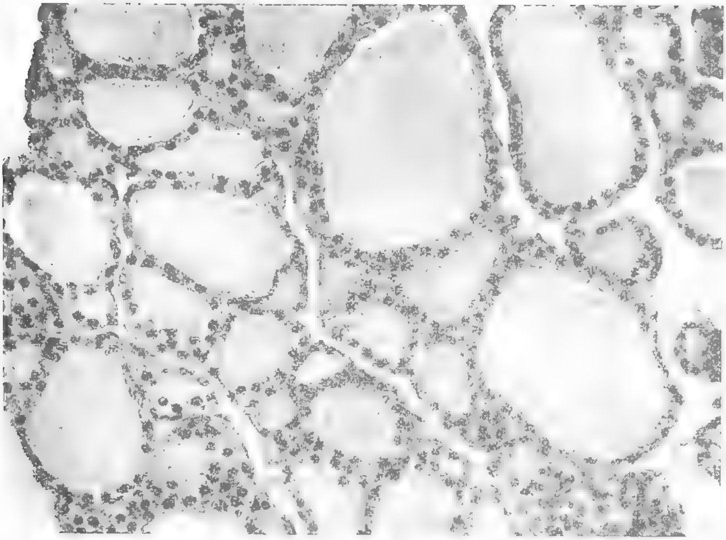

FIG. 92.—SECTION OF THYROID OF CAT. Magnified 200 diameters. Photograph.

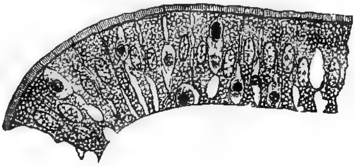

FIG. 93.

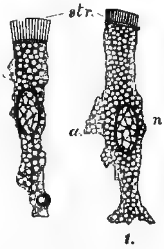

FIG. 94.

FIG. 93.—A ROW OF COLUMNAR CELLS FROM THE INTESTINE OF THE RABBIT. Smaller cells are seen between the epithelium-cells; these are leucocytes.

FIG. 94. COLUMNAR EPITHELIUM-CELLS OF THE RABBIT'S INTESTINE. More highly magnified.

The cells have been isolated after maceration in very weak chromic acid. The cells are much vacuolated, and one of them has a fat-globule adhering to it near its attached end; the striated border (*str*) is well seen, and the bright disk separating it from the cell-protoplasm; *n*, nucleus, with intranuclear network; *a*, a thinned-out wing-like projection of the cell which probably fitted between two adjacent cells.

striated border and the protoplasm of the cell is a highly refracting disk which consists of fine dumb-bell shaped particles set vertically. The striated border is connected through this disk with fibrils or striæ which run through the cell-protoplasm (figs. 95, 96). It has been suggested that the dumb-bell shaped particles are formed by multiplication of the centrosome, but the fact cannot be regarded as established. The nucleus is ovoid and reticular. The lateral borders of the cells are often somewhat irregular or jagged, the result of the presence of amœboid leucocytes, which are generally found between the columnar cells, at least in the intestine. After a meal containing fat the epithelium-cells of the small intestine contain fat globules, which become stained black in osmic preparations.

Columnar epithelium-cells are found lining the whole of the interior of the stomach and intestines: they are also present in the ducts of most glands, and sometimes also in their secreting tubes and saccules. The epithelium which covers the ovary is also of a modified columnar shape, but cells possessing the striated border and other structural peculiarities above described occur only in the alimentary canal and in its diverticula.

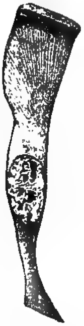

FIG. 95.

FIG. 95.—A COLUMNAR EPITHELIUM-CELL, SHOWING MASS OF FIBRILS (CYTOMITOME) WITHIN THE CYTOPLASM. (M. Heidenhain.)

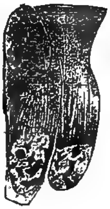

FIG. 96.

FIG. 96.—A GOBLET OR MUCUS-SECRETING CELL IN COLUMNAR EPITHELIUM. (M. Heidenhain.)

The centrosome is in the mucigen-mass. Part of an ordinary columnar cell is also shown.

Goblet-cells.—Some of the cells of most columnar epithelia (fig. 97), and also some cells in glandular, ciliated, and transitional epithelia, contain mucigen, which is laid down within the cell in the form of granules or globules of mucigen (fig. 96, fig. 98, m^1, m^2). These granules eventually swell up to form globular masses which clump together and greatly distend the part of the cell nearest the free border. When the mucigen is extruded as mucus the free part of the cell becomes emptied and the cell then takes the form of a goblet or chalice, hence the above name.

These *goblet-cells*, or as they may be appropriately termed, *mucus-secreting cells*, are probably not mere temporary modifications of the ordinary columnar and ciliated cells amongst which they are found, but permanently differentiated cells. After having got rid of their mucus by extrusion, they again form a fresh supply in the same way as before. In the gastric mucous membrane all the surface epithelium is composed of mucus secreting cells, and they extend also into the mouths of the glands. In the large intestine also most of the cells both of the surface and in the glands are goblet-cells. According to Carlier those of the gastric mucous membrane are connected together laterally by protoplasmic fibres.

Ciliated epithelium.—Ciliated epithelium is found in man throughout the whole extent of the air-passages and their prolongations, but not in the uppermost part of the nostrils which is supplied by the olfactory nerves, nor in the lower part of the pharynx, nor in the terminal bronchioles and pulmonary alveoli. Ciliated epithelium also occurs in the Fallopian tubes (oviducts) and the greater part of the uterus; in the efferent tubes of the testicle; and in the ventricles of the brain, and the central canal of the spinal cord. The cells of a ciliated epithelium are usually columnar in shape (figs. 98, 99), but in place of the striated border of the ordinary columnar cell the free surface is surmounted by a bunch of fine tapering filaments (*vibratile cilia*), which, during life, move spontaneously to and fro, and serve to produce a current in the fluid which covers them. The border upon which the cilia are set is bright in the living condition: after fixation it appears formed of little juxtaposed *knobs* or *basal particles*, to each of which a cilium is attached.

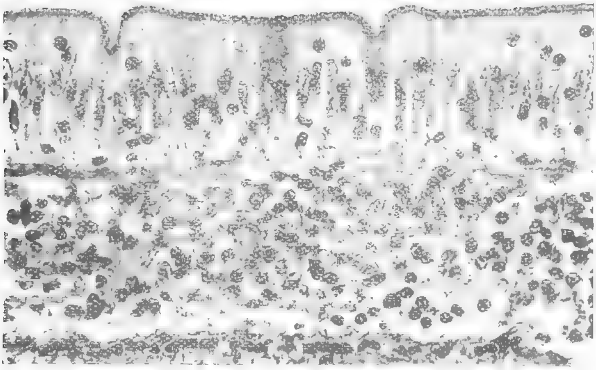

FIG. 97.—COLUMNAR EPITHELIUM COVERING THE SIDE OF A VILLUS OF THE INTESTINE (HUMAN). Magnified 200 diameters. (From a preparation by Professor Martin Heidenhain.)

One or two goblet-cells are seen amongst the ordinary cells.

In the large ciliated cells which line the alimentary canal of some molluscs (figs. 100, 101), and with less distinctness in the ciliated cells of vertebrates, the knobs may be observed to be prolonged into the protoplasm of the cell as fine varicose filaments termed the *rootlets* of the cilia. Since the axial fibril in the tail of the spermatozoon (which is undoubtedly to be regarded as a cilium) is

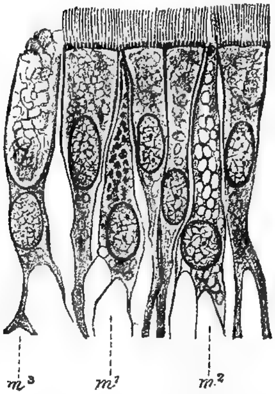

FIG. 98. CILIATED COLUMNAR EPITHELIUM, FROM THE TRACHEA OF A RABBIT.

m^1, m^2, m^3, mucus-secreting cells in various stages of mucigen formation. The preparation was treated with dilute chromic acid.

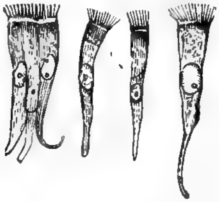

FIG. 99.—COLUMNAR CILIATED EPITHELIUM-CELLS FROM THE LOWER PART OF THE HUMAN NASAL PASSAGES. EXAMINED FRESH IN SERUM. (Sharpey.)

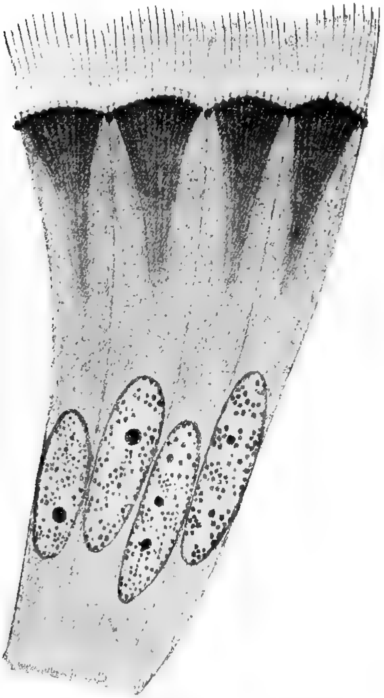

FIG. 100.—FOUR CILIATED CELLS. (v. Lenhossék.)

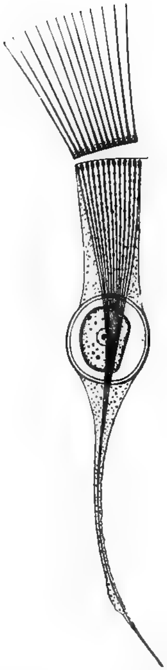

FIG. 101.—CILIATED CELL, FROM THE INTESTINE OF A MOLLUSC. (Engelmann.)

developed in connexion with the centrosome, it has been supposed that the cilia of an ordinary ciliated cell may also be outgrowths from the (multiplied) centrosome. But although it may be the case that the basal particles are formed by the division of the centrosome of the cell, in which case the rootlets may represent the fibrils of archoplasm which radiate from the centrosome of such a cell as the white corpuscle (fig. 11), it would appear that the cilia are not always developed from the basal particles, for they sometimes appear before the basal particles. In plant spores, which have no centrosomes, the cilia are developed from amœboid processes of the ectoplasm of the cell (Strassburger). Similar basal particles and longitudinal fibrils are found in columnar cells (p. 74); these are probably homologous with the knobs and rootlets of the ciliated cell, while the bunch of cilia of the latter is perhaps represented by the striated border of the columnar cell.

According to H. E. Jordan, amitosis is the ordinary form of cell division in ciliated epithelium; he connects this with the transformation of the centrosomes above-mentioned.

The action of cilia.—When in motion a cilium is bent quickly over in one direction with a lashing whip-like movement, immediately recovering itself. When vigorous the action is so rapid, and the rhythm so frequent (ten or more times in a second), that it is impossible to follow the motion with the eye. All the cilia upon a ciliated surface are not in action at the same instant, but the movement travels in waves over the surface. If a cell is detached from the general surface, its cilia continue to act for a while, but their movement at once ceases if they are detached from the cell. If, however, a portion of the cell-protoplasm is detached with them, they will continue to move for a time.

The rhythm is slowed by cold, quickened by warmth; but heat a few degrees above body temperature kills the cells. The movement will continue for some time in water deprived of oxygen. Both CO_2 gas and ether and chloroform vapour arrest the action, but it recommences on restoring air, if the action is not too prolonged. Dilute alkaline solutions quicken the activity of cilia, or may even restore it shortly after it has ceased.

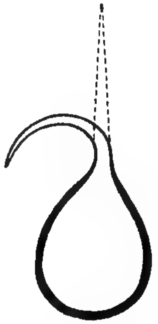

Fig. 102. — Model to illustrate the action of a cilium.

Theories of ciliary action.—Various attempts have been made to explain the manner in which cilia act. One hypothesis supposes that one side only of each cilium is contractile, the other side being elastic, or that there is a more rigid but elastic axis and a contractile covering. It is, however, impossible that a soft structure like a cilium could be bent over in a uniform curve by contraction along one side; such contraction could only produce shortening and wrinkling of the cilium, effects which are never observed. Another hypothesis assumes that the projecting cilia are set in action by rhythmic lateral contractions in the protoplasm; which, by moving the rootlets, cause the cilia to bend over as a whip is bent by movements of the wrist applied to its handle. But this again implies an amount of rigidity which neither the cilia nor the rootlets possess, and it must be borne in mind that cilia have to overcome the resistance of fluid, and of fluid which is in many cases highly viscous.

The most reasonable hypothesis to explain the mode of action of cilia appears to be that they are hollow filaments, with a fluid interior communicating with the cell-protoplasm.[1] If this is so, alterations of pressure in the cell, caused by changes in surface tension, would drive fluid into and out of the cilia, and if we assume them to be naturally curved this movement must cause the curve to open out with increase, and straighten again with diminution of pressure. An action of this kind can be imitated with a curved flattened flexible tube attached to a pressure bag (fig. 102). Increase of pressure causes the tube to straighten out; on decreasing the pressure the tube bends over exactly in the manner of a cilium. This hypothesis has the advantage over others which have been offered that it explains the movements of cilia on a theory which is similar to that which gives the most probable explanation of amœboid movements of protoplasm, viz., that they are due to variations in surface tension, and it thus brings these two forms of protoplasmic activity into line with one another. It will presently be seen that the changes which occur in muscle in contraction are susceptible of a similar explanation.

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[1] Every cilium or cilium-like structure (flagellum) which is sufficiently large to show any structural differentiation, exhibits an external membranous covering and clear homogeneous contents. Some observers have described alternate darker and lighter shadings in the cilia of the fresh-water mussel.

LESSON IX.

THE CONNECTIVE TISSUES.

1. TAKE a little of the subcutaneous tissue or of the intermuscular connective tissue of a rabbit or guinea-pig and spread it out with needles on a dry slide into a large thin film. Keep the centre moist by occasionally breathing on it, but allow the edges to dry to the slide. Before commencing put a drop of salt solution on a cover-glass, and now invert this over the film. Examine with a high power. Sketch one or two bundles of white fibres and also one or two elastic fibres, distinguishable from the former by their sharp outline, isolated course, and by their branching. Sketch also one or more connective-tissue corpuscles, if any such are visible in the clear interspaces. Look also for migratory cells (leucocytes). Next carefully remove the cover-glass and replace the salt solution by dilute acetic acid (1 per cent.). Watch its effect in swelling the white fibres and bringing more clearly into view the elastic fibres and corpuscles. Look for constricted bundles of white fibres.

2. Make another very thin film in the same way, but allow to dry almost completely. Pour over the film a 1 per cent. solution of magenta (fuchsin) in equal parts of water and alcohol, to which 1 drop per cubic centimeter of a 1 per cent. solution of gentian violet in alcohol has just been added. After one minute drain off, remove the remainder of the staining solution by filter paper, and allow the film to dry. When completely dry mount in dammar. The elastic fibres are deeply stained ; the cells are also shown.

Mallory's stain (see Appendix), which contains acid fuchsin, is useful for staining connective-tissue fibres in sections of organs.

3. Prepare another film of the subcutaneous tissue, including a little adipose tissue. Fix by pouring over it formol (10 per cent.) and leave this in contact with the film for 20 minutes. Wash with water and stain with saturated solution of Sudan III. or Scharlach R. in 75 per cent. alcohol ; wash with 75 per cent. alcohol to remove stain from everything except fat, then wash with water and counter stain with dilute hæmatoxylin. Mount in dilute glycerine. Examine first with a low and afterwards with a high power. The fat is well brought out by the Sudan III. or Scharlach R. stain ; if the preparation is from a young animal, fat-cells will be found in process of formation. Measure and sketch two or three of the fat-cells.

The fat may also be stained without prior fixation, by treatment with 1 per cent. osmic acid solution, which colours it intensely black.

4. Spread out another film of connective tissue, letting its edges dry to the slide, but keeping the centre moist by the breath. Place on its centre a large drop of nitrate of silver solution (1 per cent.). After five minutes wash this away with distilled water, and expose to direct sunlight until slightly brown. Now allow the film to dry completely, and cover it in dammar. Sketch the outlines of some of the cell-spaces which are displayed.

5. For retiform tissue the following method is recommended (Spalteholz). Place a piece of the organ (*e.g.* lymphatic gland) for twenty-four hours or more in alcohol, then overnight at 38° C. in a 1 per cent. solution of carbonate of soda to which a few drops of a solution containing trypsin have been added. Cautiously transfer the semi-digested structure to alcohol again, and leave it for a few hours. Embed in paraffin in the usual way and stain the sections with iron hæmatoxylin

(see Appendix). The fibrils of connective and retiform tissue are the only structures which have remained undigested and they are deeply coloured by the hæmatoxylin.

Retiform tissue is also well shown in sections of lymph glands stained with Mallory's or Van Gieson's stains (see Appendix).

The **connective tissues** include *areolar* tissue, *adipose* tissue, *elastic* tissue, *fibrous* tissue, *reticular* and *lymphoid* tissue, *cartilage* and *bone.* All these tissues agree in certain microscopic and chemical characters. They, for the most part, have a large amount of intercellular substance in which fibres are developed, and these fibres are of two kinds—*white* and *yellow* or *elastic*; there are many points of similarity between their cells; they are all developed from the same embryonic formation; and where they come in contact in the body they tend to pass imperceptibly the one into the other. Besides this, the use made of these several tissues in the body is similar; for they mostly serve to connect and support the other tissues, thus performing a purely passive or mechanical function. They are for these reasons grouped together, although they differ considerably in external and even in microscopic characters. Of all these connective tissues there are however three which are so intimately allied that they must be described together, for they are composed of exactly the same elements, and differ only in the relative development of those elements: these three are the areolar, elastic, and fibrous tissues. Further, adipose tissue and reticular tissue are to be looked upon as special modifications of areolar tissue.

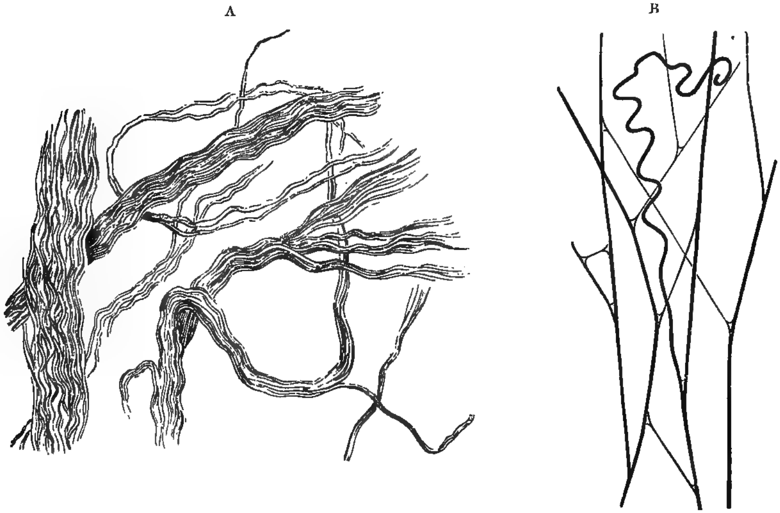

FIG. 103.—WHITE AND ELASTIC FIBRES OF AREOLAR TISSUE.
A, bundles of white fibres partly unravelled. *B*, elastic fibres.

Areolar tissue being the commonest and, in a sense, the most typical, its structure may be considered first.

AREOLAR TISSUE.

Areolar tissue presents to the naked eye an appearance of fine transparent threads and laminæ which intercross in every direction with one another, leaving intercommunicating meshes, or areolæ, between them When examined with the microscope, these threads and fibres are seen to be principally made up of wavy bundles of exquisitely fine transparent fibres (*white fibres*, fig. 103, A). The bundles run in different directions, and may branch and intercommunicate with one another (fig. 106); but the individual fibres, although they pass from one bundle to another, never branch or join other fibres. The fibres are cemented together into the bundles by a clear substance containing mucin, and the same semi-fluid material forms also the basis or *ground-substance* of the tissue, in which the bundles themselves course, and in which also the corpuscles of the tissue lie embedded. This ground-substance between the bundles can with difficulty be seen in the fresh tissue on account of its extreme transparency; but it can be brought to view by treatment with nitrate of silver (§ 4). The whole of the tissue is thereby stained of a yellowish-brown colour, with the exception of the spaces which are occupied by the corpuscles (*cell-spaces*, fig. 104). As Macallum has shown, this reaction is due to the presence of chlorides in the intercellular substance.

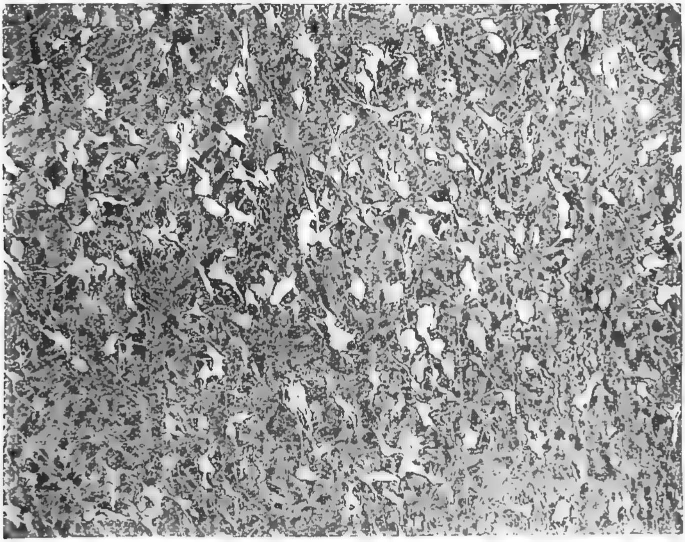

FIG. 104.—AREOLAR TISSUE PREPARED BY RECKLINGHAUSEN'S SILVER METHOD. Magnified 200 diameters. Photograph.

The cells are seen as clear spaces in the (brown) stained ground-substance, through which the fibres course.

Besides the white fibres of connective tissue here described, fibres of a different kind (fig. 103, B) may be made out in the preparations; these are the *elastic fibres.* They are especially well seen after treatment with acetic acid, and after staining with magenta, or, in sections, with orcein; but they can be detected also in fresh preparations. They are characterised by their distinct outline, their straight course, the fact that they never run in bundles, but singly, and that they branch or join neighbouring fibres. If broken by the needles in making the preparation, the elastic recoil causes them to curl up, especially near the broken ends. Besides these histological differences,

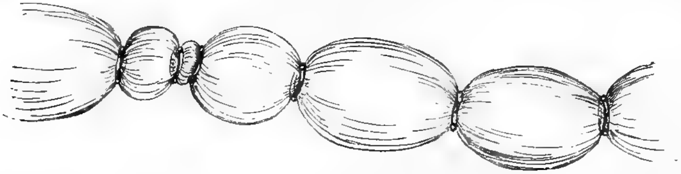

FIG. 105.—A WHITE BUNDLE SWOLLEN BY ACETIC ACID. FROM THE SUB-ARACHNOID TISSUE AT THE BASE OF THE BRAIN. (Toldt.)

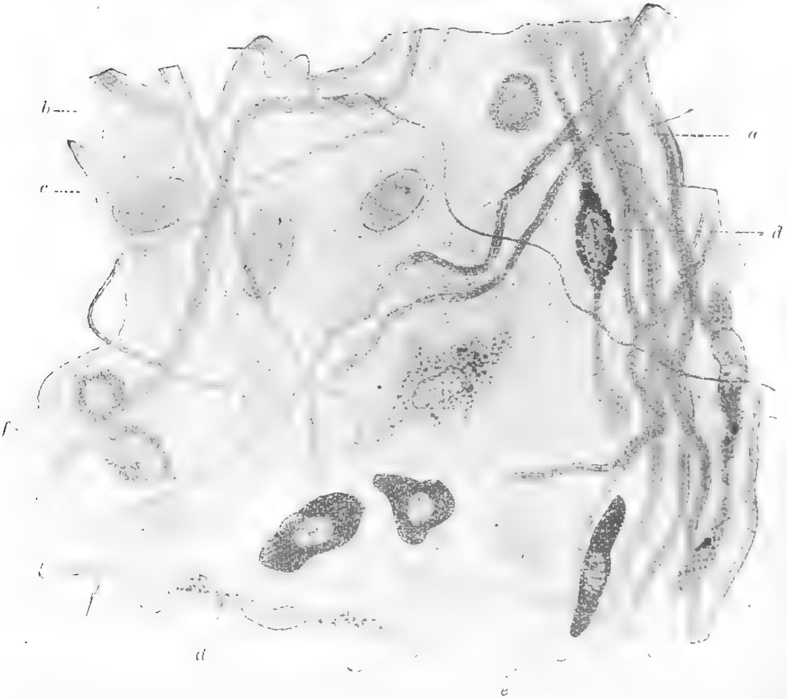

FIG. 106.—FIBRES AND CELLS OF AREOLAR TISSUE OF A GUINEA-PIG FROM A FILM PREPARATION. (Maximow.) The preparation was stained, without fixation, by neutral red.

a, bundles of white fibres; *b*, elastic fibres; *c*, lamellar cells; *d*, clasmatocytes; *e*, plasma-cells; *f*, oxyphil leucocytes.

the two kinds of fibre differ also in their chemical characters. Thus the white fibres are formed of a material (*collagen*) which is dissolved by boiling in water, forming a solution of gelatin; they are also dissolved by peptic digestion, but not by tryptic; whereas the substance of which the elastic fibres are composed (*elastin*) resists for a long time the action of boiling water and peptic digestion, and is dissolved by tryptic digestion. Moreover, the white fibres swell and become indistinct under the action of dilute acetic acid; the elastic fibres are unaltered by this reagent. Elastic fibres appear to have a sheath which is more resistant to reagents than the rest of the fibre.

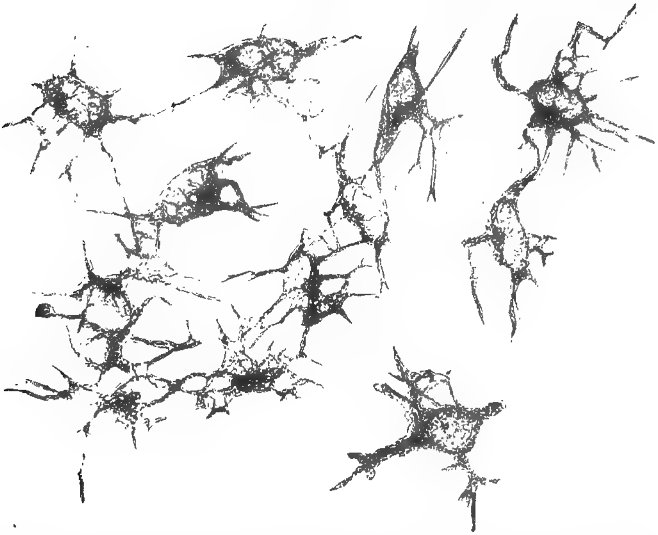

FIG. 107.—CELLS OF RABBIT'S CORNEA STAINED WITH GOLD CHLORIDE. Magnified 300 diameters.

The nuclei are unstained. The cells are connected by their branches.

Bundles of white fibres which have been swollen out by acid sometimes exhibit constrictions at irregular intervals (fig. 105). These constrictions are thought to be due to elastic fibres coiling round the white bundles.

The cells of areolar tissue.—Several varieties of connective-tissue cells are distinguished, viz.: (1) *Lamellar cells*, which are flattened and often branched (fig. 106, *c*, *c′*), and may be united one to the other by their branches, as in the cornea (fig. 107). Sometimes these cells are unbranched; they may lie along the fibril-bundles and even themselves show a fibrillar appearance.[1] In certain situations the lamellar connective-tissue cells are greatly flattened out, especially when they lie upon the surface of aponeuroses where they are joined edge to edge like the cells of an endothelium (fig. 109). The apparent cell-spaces in silver preparations have of course in all cases

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[1] Some authors have inferred from this that these cells are transformed into white fibril-bundles and have termed them "fibroplasts"; but the fibrillation which they exhibit is not of the same character as that of the white fibres, and is probably a form of cytomitome, such as is seen in many cells.

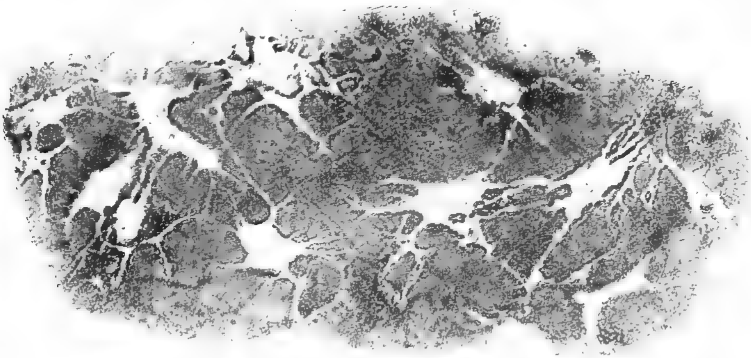

FIG. 108. CORNEA OF RABBIT, STAINED WITH SILVER NITRATE. Magnified 300 diameters. Photographed from a preparation by H. Pringle.

The cells are unstained, and appear as white spaces on a brown ground. Compare with fig. 107, in which the cells are stained.

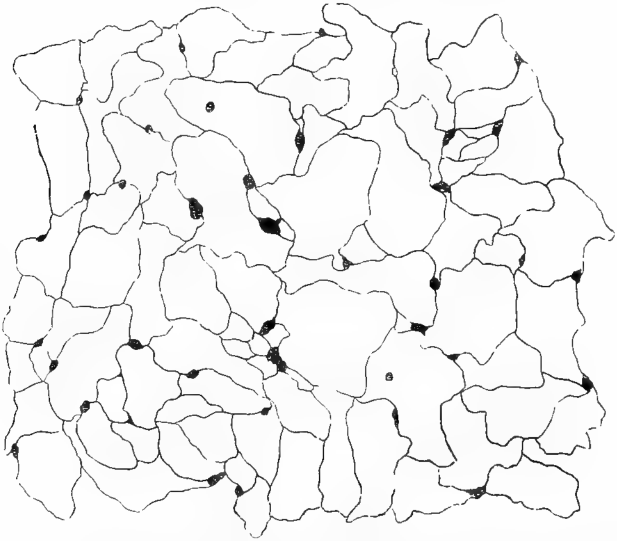

FIG. 109.—EPITHELOID CELLS OF CONNECTIVE TISSUE FROM THE SURFACE OF AN APONEUROSIS. NITRATE OF SILVER PREPARATION.

a similar arrangement to that of the cells. (2) *Clasmatocytes*, which are composed of a soft, much-vacuolated, often granular protoplasm, rarely flattened, but otherwise varying greatly in shape and size (fig. 106, *d*). (3) *Mast-cells* (Ehrlich), usually spheroidal or ovoidal in shape, filled with granules, which are deeply stained by gentian violet and by other basic aniline dyes. They are not everywhere common, but are numerous in parts where fat is being laid down (figs. 112, 113). (4) *Plasma-cells* (fig. 106, *e*). These are characterised by their granular protoplasm, which is less basiphil than that of the mast-cells and their relatively small nucleus; in shape, they are either rounded, angular, or elongated.

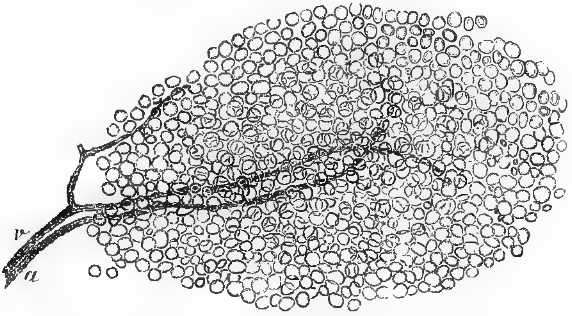

FIG. 110.—A SMALL LOBULE OF ADIPOSE TISSUE. Magnified 20 diameters.
a, *v*, small artery and vein entering the lobule.

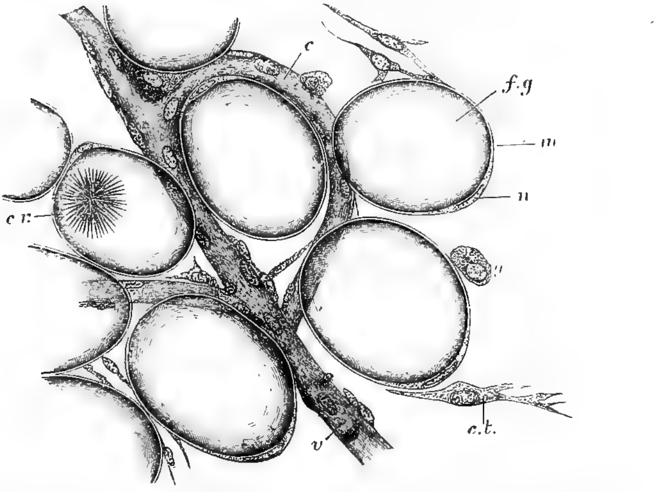

FIG. 111.—A FEW CELLS FROM THE MARGIN OF THE FAT LOBULE SHOWN IN FIG. 110. Highly magnified.
f.g., fat-globule distending a fat-cell; *n*, nucleus; *m*, membranous envelope of the fat-cell; *c.r.*, bunch of crystals within a fat-cell; *c*, capillary vessel; *v*, veinule; *c.t.*, connective-tissue cell; *g*, granular cell. The connective-tissue fibres are not represented.

Migratory leucocytes may also (fig. 106, *f*) be seen here and there in areolar tissue (*wander-cells*).

In the middle coat of the eye in mammals, and in some parts of the skin, some of the connective-tissue cells are occupied by granules of pigment (*pigment-cells*).

These are much more extensively present in lower vertebrates, especially in Amphibia and fishes, where they exhibit amœboid changes which result in the pigment being at one time diffused over a considerable area and at another time restricted to the immediate neighbourhood of the nucleus. The changes thus produced cause alteration in the general colour and shade of the integument, where such pigment-cells are very numerous, and serve the purpose of protective adaptation of the animals to their environment.

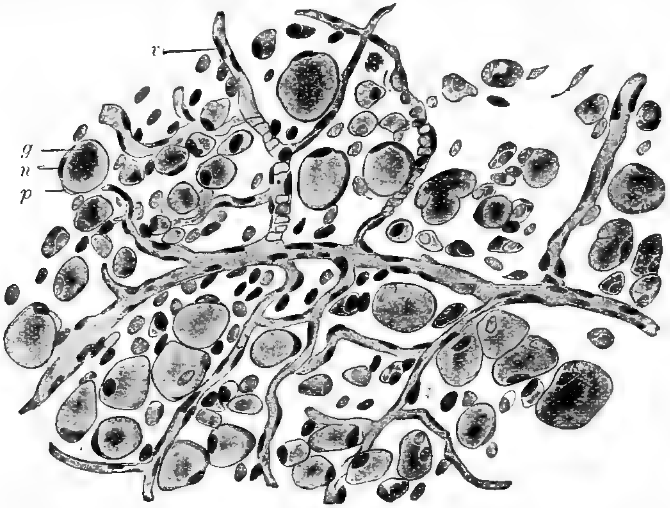

FIG. 112.—FAT IN MESENTERY OF RABBIT. (From Prenant, Bouin, and Maillard.)

r, network of capillary vessels; *g*, fat-globule; *n*, nucleus of fat-cell; *p*, protoplasmic envelope to fat-globule.
Numerous mast-cells are seen: in some of these there appears to be occurring a deposition of fat.

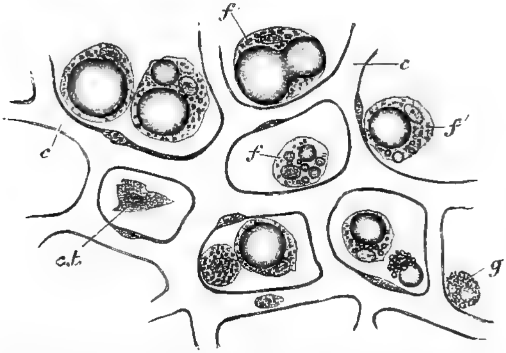

FIG. 113.—DEPOSITION OF FAT IN CONNECTIVE-TISSUE CELLS.

f, a cell with a few isolated fat-droplets in its protoplasm; f', a cell with a single large and several minute drops; f'', fusion of two large drops; *g*, granular mast-cell; *c.t.*, lamellar connective-tissue corpuscle; *c.c.*, network of capillaries.

The connective-tissue cells occupy spaces of corresponding shape in the ground-substance (fig. 108), between the bundles of white fibres. In some parts of the connective tissue the white bundles are developed to such an extent as to pervade almost the whole of the ground-substance, and then the connective-tissue corpuscles become squeezed into the interstices, flattened lamellar expansions of the cells extending between the bundles, as in tendon (see next Lesson).

The cells and cell-spaces of areolar tissue come into intimate relation with the cells lining the lymphatic vessels and small blood-vessels. This connexion can best be seen in silvered preparations; it will be again referred to in speaking of the origin of the lymphatics.

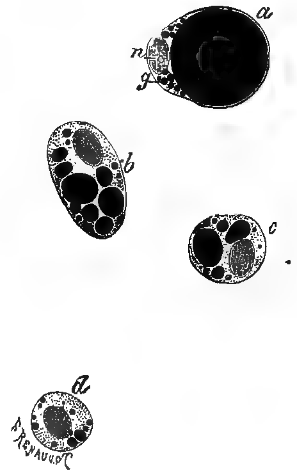

FIG. 114. — FAT-CELLS FROM YOUNG ANIMAL. (Ranvier.) OSMIC ACID PREPARATION.

The drops of fat are stained of an intense black. *n*, nucleus; *g*, small globules of fat.

ADIPOSE TISSUE.

Adipose tissue consists of vesicles filled with fat (figs. 110, 111) and collected into lobules, or into tracts which accompany the small blood-vessels. The vesicles are round or oval in shape, except where closely packed, when they become polyhedral from mutual compression. The fat-drop is contained within a delicate protoplasmic envelope (fig. 111, *m*) which is thickened at one part, and here includes an oval flattened nucleus. The fat is stained black by osmic acid (fig. 114); a deep yellow colour by Sudan III.; and an intense red by Scharlach R. The vesicles are supported partly by filaments of areolar tissue, but chiefly by a fine network of capillary blood-vessels.

The fat when first formed in the embryo is deposited within large granular cells (fig. 115) of a spheroidal or polyhedral shape; some authorities regard these cells as of a specific nature, for they are in certain situations collected into gland-like masses abundantly supplied with blood-vessels. They gradually become transformed into fat-cells by the deposition of fat in the cell-protoplasm. Fat is, however, also laid down in other situations in ordinary cells of connective tissue. In all cases the fat appears to be produced by a transformation into droplets of fat of albuminous granules which the cells contain. As the droplets increase in size they run together into a larger drop, which gradually fills the cell more and more, swelling it out so that the cell-protoplasm eventually appears merely as the envelope of the fat-vesicle. Fat-cells often contain lipoid globules as well as true fat, and it is possible that in its development the fat in the cell is always preceded by lipoid matter.

Fat is found most abundantly in subcutaneous areolar tissue, and under the serous membranes; especially in some parts, as at the back of the peritoneum around the kidneys, under the epicardium, and in the mesentery and omentum. The yellow marrow of the bones is also principally composed of fat. There is no adipose tissue within the cavity of the cranium.

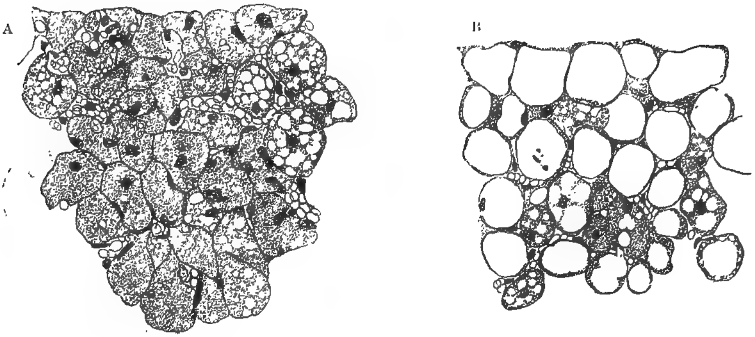

FIG. 115.—TWO STAGES OF FORMATION OF ADIPOSE TISSUE. (H. Batty Shaw.)

In *A* the tissue is formed of a gland-like mass of cells, in some of which the cytoplasm is occupied by fat-globules (looking white in the sections). In *B* the fat fills many of the cells.

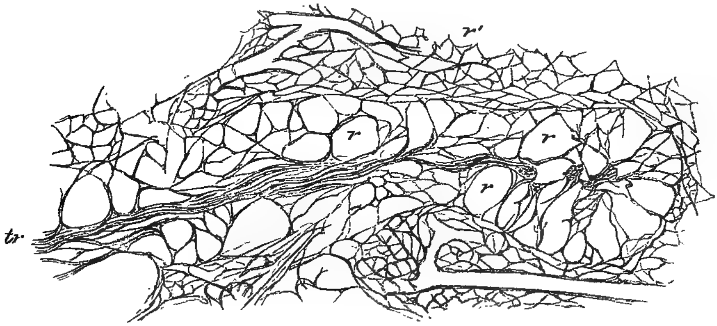

FIG. 116.—RETIFORM TISSUE FROM A LYMPH-GLAND. Moderately magnified.

tr, a trabeculum of connective tissue; *r*, *r'*, retiform tissue, with more open meshes at *r* and denser at *r'*.

RETICULAR AND LYMPHOID TISSUE.

In **retiform or reticular tissue** (figs. 116, 117, 118) the intercellular substance is largely replaced by fluid which is traversed by a network of white fibres, the meshes of which vary in size, being very small and close in some parts; more open and like areolar tissue in other parts. There are few or no elastic fibres. The fibres are often enwrapped by flattened branched connective-tissue cells, which must be removed to bring the fibres clearly into view. Chemical differences between the fibres of retiform tissue and those of ordinary areolar tissue have been described, but microscopically the fibres of the two tissues are indistinguishable: they are stained by the same reagents and occur in complete continuity with one another (see figs. 116, 117, 119). Reticular tissue forms a fine framework in many organs; supporting the proper elements and extending into the interstices between the coarser connective-tissue bundles. It can be well shown by dissolving the cells of the tissue by tryptic digestion and subsequently staining the fibres forming the reticulum (p. 79, § 5). It occurs characteristically in lymph-glands, but may also be displayed in the spleen, liver, bone-marrow (fig. 118), mucous membranes, and many other parts.

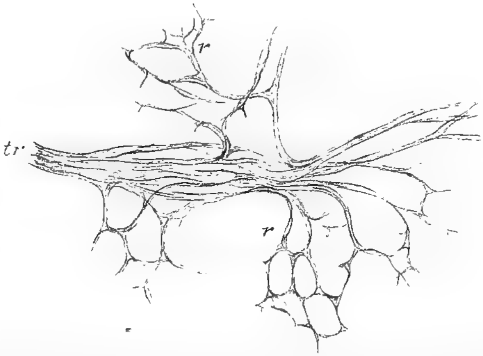

FIG. 117.—PORTION OF THE ABOVE, MORE HIGHLY MAGNIFIED.
Showing the continuity of the retiform tissue, *r*, *r*, with the connective tissue of a trabeculum, *tr*.

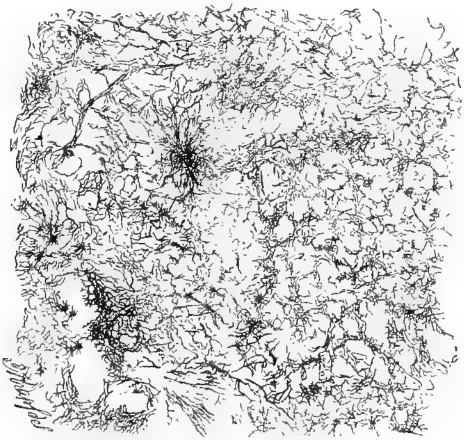

FIG. 118.—RETICULUM OF BONE-MARROW. (Enderlen.)

Lymphoid or **adenoid tissue** is reticular tissue in which the meshes of the network are largely occupied by lymph-corpuscles (fig. 119). This is met with in the lymph-glands and in allied structures, such as the tonsils, lymphoid follicles, and Malpighian corpuscles of spleen.

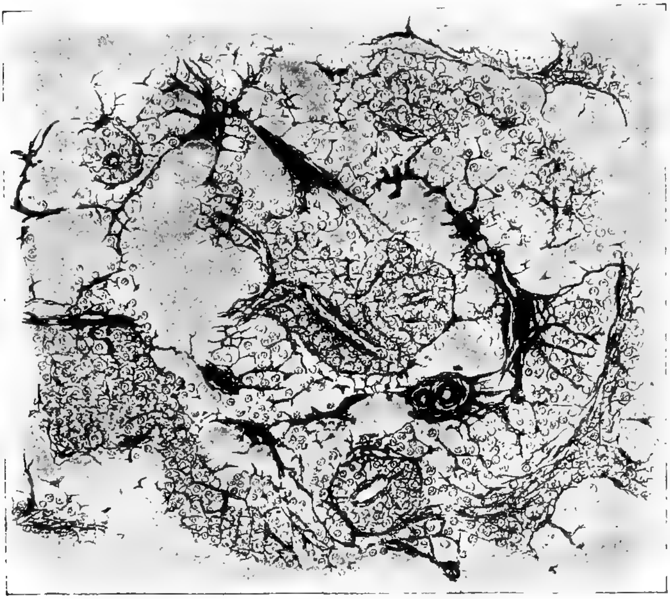

FIG. 119.—LYMPHOID TISSUE OF A LYMPH-GLAND.

The fibres of the tissue have been stained by fuchsin. Their continuity with the connective-tissue trabeculæ is in this way well shown.

LESSON X.

THE CONNECTIVE TISSUES (*continued*).

1. **Tease** out as finely as possible a small shred of elastic tissue (ligamentum nuchæ of the ox or ligamentum subflavum of man) in glycerine and water, slightly tinged by magenta. Cover and cement the preparation. Note the large well-defined fibres constantly branching and uniting with one another. Sketch a small part of the network. Note the existence of bundles of white fibres amongst the elastic fibres.

2. Examine a thin transverse section of ligamentum nuchæ which has been hardened in 2 per cent. solution of bichromate of potassium. The section is to be stained with hæmatoxylin and mounted in dammar by the usual process, or simply in glycerine and water. Observe the grouping of the fibres and their angular shape. Frequently the angles are rounded.

3. Pinch off the end of the tail of a dead mouse or rat, draw out the long silk-like tendons and put them into salt solution. Take one of the threads, which should be nearly three inches long, and stretch it along a slide, letting the ends dry firmly to the glass but keeping the middle part wet. Put a short piece of hair on each side of this and cover in salt solution. Observe with a high power the fine wavy fibrillation of the tendon. Draw. Now run dilute acetic acid (0·75 per cent.) under the cover-glass; watch the tendon where it is becoming swollen by the acetic acid. Notice the oblong nucleated cells coming into view between the tendon-bundles. Sketch three or four cells in a row. Lastly, lift the cover-glass, wash away the acid with distilled water, place a drop of hæmatoxylin or carmalum solution on the tendon, and leave the preparation until it is deeply stained; then wash away the stain and mount the preparation in faintly acidulated glycerine.

4. Take another long piece of rat or mouse tail tendon, and after washing it in distilled water, stretch it upon a slide as before, fixing the ends by allowing them to dry on to the slide but keeping the middle wet. Put a drop of nitrate of silver solution (1 per cent.) on the middle, and leave it for five minutes. Then rinse off the silver nitrate with distilled water, drain this off and expose the slide to direct sunlight. In a very few minutes the silvered part of the tendon will be brown. Allow it to dry completely and then mount in dammar.

5. Stain with magenta solution a thin section of ox tendon which has been hardened in 70 per cent. alcohol. The section may be cut by hand with a razor, or a small piece of the tissue may be soaked in gum and cut frozen. Mount in dilute glycerine and cement at once.

6. For studying the development of connective tissue, sections of the umbilical cord at different periods may be used. Fix with formol. Stain with acid fuchsin.

ELASTIC TISSUE.

Elastic tissue is a variety of connective tissue in which the elastic fibres preponderate. It is found most characteristically in the ligamentum nuchæ of quadrupeds and the ligamenta subflava of the vertebræ, but the connective tissue of other parts may also have a considerable development of elastic fibres. It occurs in an almost pure form in the walls of the air-tubes, and uniting the cartilages of the larynx. It also enters largely into the formation of the lungs and of the walls of the arteries.

In the ligamentum nuchæ most of the fibres are large (figs. 120, 121).

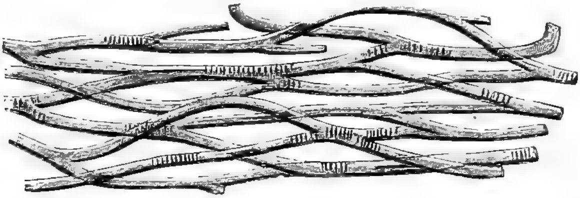

FIG. 120.—ELASTIC FIBRES FROM THE LIGAMENTUM NUCHÆ OF THE OX, SHOWING TRANSVERSE MARKINGS ON THE FIBRES.

They often exhibit cross markings or even transverse clefts. When dragged asunder, they break sharply across. They constantly branch and unite, so as to form a close network. In transverse section they appear angular, but usually the angles are rounded (fig. 121). They are separated into small groups or bundles by intervening areolar tissue.

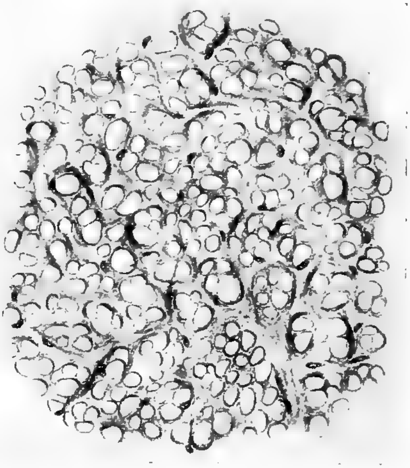

FIG. 121.—CROSS-SECTION OF ELASTIC FIBRES FROM THE LIGAMENTUM NUCHÆ OF THE OX.

The angles of the fibres are rounded.

Elastic tissue does not always take the form of fibres, but may occur as membranes (*e.g.* in the blood-vessels). In areolar tissue the elastic fibres may be very fine, but their microscopic and chemical characters are always well marked (p. 82).

FIBROUS TISSUE.

Fibrous tissue is almost wholly made up of bundles of white fibres running in a determinate direction. These again are collected into larger bundles, which give the fibrous appearance to the tissue. The bundles are constantly uniting with one another in their course, although their component fibres remain perfectly distinct.

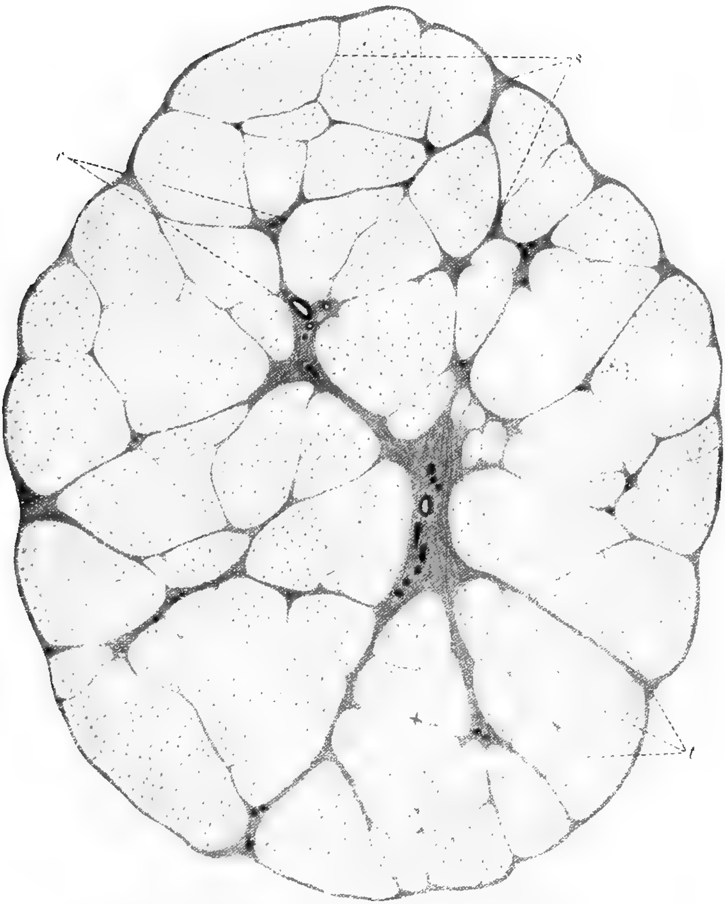

Fig. 122.—Section of tendon, human. (Sobotta.) × 32.
t, tendon-bundles; *s*, septa of areolar tissue; *v*, vessels.

The interspaces between the larger bundles are occupied by areolar tissue (fig. 122, *s*; fig. 123, *c*, *d*, *e*) in which the blood-vessels and lymphatics of the fibrous tissue are conveyed. The interstices between the smallest bundles are occupied by rows of lamellar connective-tissue corpuscles (*tendon-cells*).

which, from being squeezed up between three or more bundles, become flattened out in two or three directions. In transverse section the cells look irregularly stellate (figs. 123, 124), but when seen on the flat they appear lamellar (fig. 125, A; fig. 126), and from this aspect their general shape is square or oblong. They lie, as before said, in rows between the tendon-bundles; the nuclei of adjacent cells are placed opposite one another in pairs (fig. 126). The cell-spaces correspond in general figure and arrangement to the cells which occupy them (fig. 125, B).

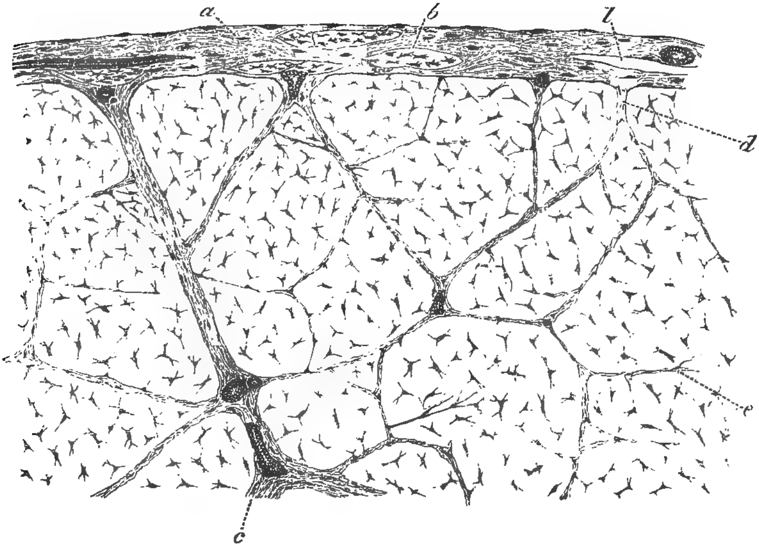

FIG. 123.—PART OF A LARGE TENDON IN TRANSVERSE SECTION. More highly magnified.

a, areolar sheath of the tendon, with the fibres for the most part running transversely; but with two or three longitudinal bundles, *b*; *l*, lymphatic cleft in the sheath; immediately over it a blood-vessel is seen cut across, and on the other side of the figure a small artery is shown cut longitudinally; *c*, large septum of areolar tissue; *d*, smaller septum; *e*, still smaller septum. The irregularly stellate bodies are the tendon-cells in section.

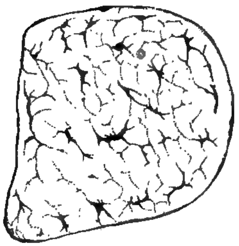

FIG. 124.—SECTION OF TENDON FROM TAIL OF MOUSE. Magnified 150 diameters.

The dark branched bodies are sections of the tendon-cells.

Fibrous tissue forms the tendons and ligaments, and also certain membranes, such as the dura mater, the fibrous pericardium, the fasciæ of the limbs, the fibrous coverings of organs, etc. It is found wherever great strength, combined with flexibility, is concerned. It receives a few blood-vessels, disposed longitudinally for the most part, and contains many lymphatics. Both blood-vessels and lymphatics run in the areolar tissue which separates and surrounds the tendon-bundles. Tendons and ligaments also receive nerve-fibres, many of which end in localised ramifications within fusiform enlargements of the tendon-bundles (organs of Golgi), while others terminate in end bulbs or in simple Pacinian corpuscles. These will be described with the modes of ending of nerve-fibres.

MINOR VARIETIES OF CONNECTIVE TISSUE.

Basement-membranes (*membranæ propriæ*) are homogeneous-looking membranes, which are found forming the surface layer of the connective-tissue expansions in certain parts, especially where there is a covering of epithelium, as on mucous membranes, in secreting glands, and elsewhere. They are sometimes formed of flattened connective-tissue cells joined together to form a membrane; but in most cases (*e.g.* front of cornea, trachea) they are evidently formed not of cells, but of condensed ground-substance, and in yet other cases of elastic substance (back of cornea); the name basement-membrane is therefore used to denote structures of an entirely different nature.

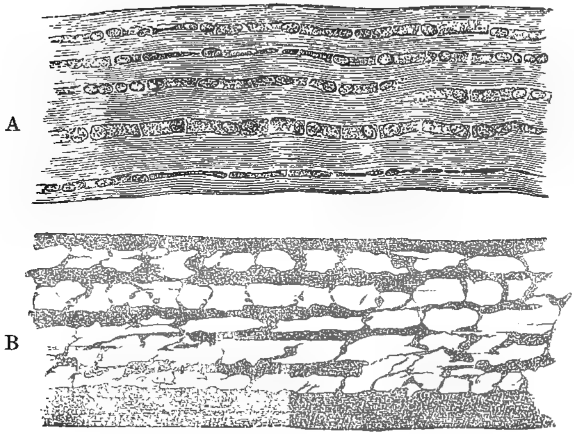

FIG. 125.—TENDONS OF MOUSE TAIL; SHOWING CHAINS OF CELLS BETWEEN THE TENDON-BUNDLES. 175 diameters.
A, stained with hæmatoxylin; *B*, stained with silver nitrate, showing the cell-spaces.

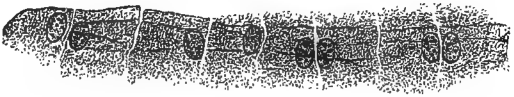

FIG. 126.—EIGHT CELLS FROM THE SAME TENDON AS REPRESENTED IN FIG. 125, A. Magnified 425 diameters.
The dark lines on the surface of the cells are the optical sections of lamellar extensions directed towards or away from the observer.

Jelly-like connective tissue, although occurring largely in the embryo, is found only in one situation in the adult—viz., forming the vitreous humour of the eye. It is composed mainly of soft, fluid, or semi-fluid

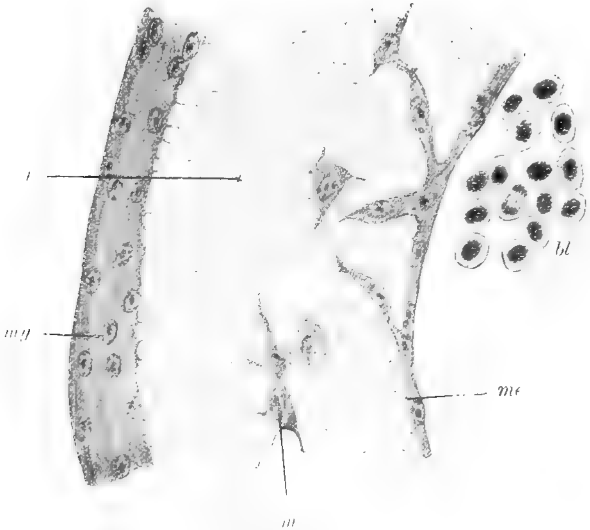

Fig. 127.—Developing connective tissue in heart of chick-embryo of 48 hours. (Szily.)

my, cells forming myocardium; *j*, jelly formed of reticulum with enclosed fluid; *e*, endothelium (mesothelium) of heart; *m*, mesenchyme cells in jelly; *bl*, blood-corpuscles.

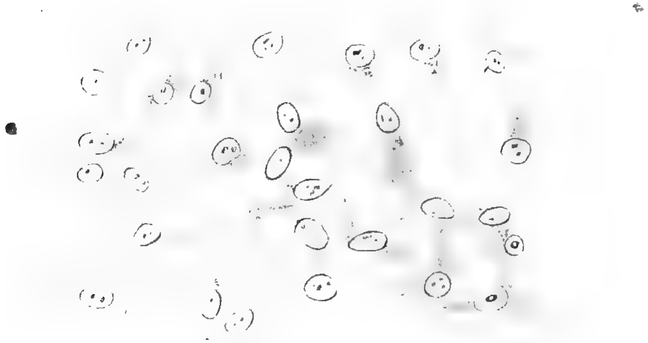

Fig. 128.—Cells of developing connective tissue (mesenchyme) united to form a syncytium. (From Prenant, Bouin, and Maillard.)

No fibres are as yet developed in the intercellular substance.

ground-substance, with cells scattered here and there through it, and with a few fibres which interlace throughout the tissue and confine the fluid of the ground-substance within their meshes; thus conferring upon the tissue its jelly-like character. All embryonic connective tissue is at one period of this jelly-like nature (see below).

DEVELOPMENT OF CONNECTIVE TISSUE.

Connective tissue is developed in and from certain cells of the mesoderm (mesenchyme) of the embryo. In those parts which are to form connective tissue, there may frequently be seen a clear space separating the cell-layers which are already formed, this clear space being sometimes permeated with fibres which appear to be produced from the cells bounding the space. Presently branching mesenchyme cells, which are budded off from the bounding cells, are found forming a syncytium within the clear space (fig. 127, *m*; fig. 128). In the meshes of the reticular syncytium is a muco-albuminous semi-fluid intercellular substance (ground-substance).

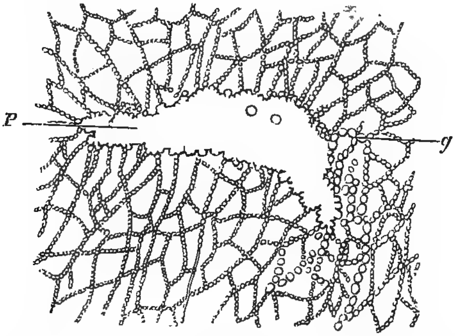

FIG. 129.—DEVELOPMENT OF ELASTIC TISSUE BY DEPOSITION OF FINE GRANULES. (Ranvier.)

g, fibres being formed of rows of "elastin" granules; *p*, flat plate-like expansion of elastic substance formed by the fusion of "elastin" granules.

The connective-tissue fibres, both white and elastic, are deposited in this ground-substance, the elastic substance appearing in the form of granules (fig. 129, *g*), which subsequently become connected together into elastic fibres or laminæ, as the case may be, the white fibres appearing at first in the form of very fine bundles (fig. 130), which afterwards become gradually larger; so that in fibrous tissue the whole ground-substance is eventually pervaded by the bundles, and the cells of the tissue become squeezed up into the intervals between them. Before any considerable development of fibres has taken place, the embryonic connective tissue has a jelly-like appearance; in this form it occurs in the umbilical cord, where it is known as the *jelly of Wharton.*

There has been always a considerable difference of opinion as to the origin of the fibres of connective tissue, some histologists holding that they are formed within the protoplasm of the cells, which gradually lose their cell-characters as the fibres become developed within them; others taking the view that the fibres, both white and elastic, are extracellular formations. While there is no doubt that they are produced under the influence of the cells, for they first appear in close proximity to those structures, it seems on the whole probable that the fibres are deposited in the ground-substance and not actually in the cell-protoplasm, so that they are rather to be looked upon, like the ground-substance itself, as formed by a process of secretion than by one of direct cell-transformation.

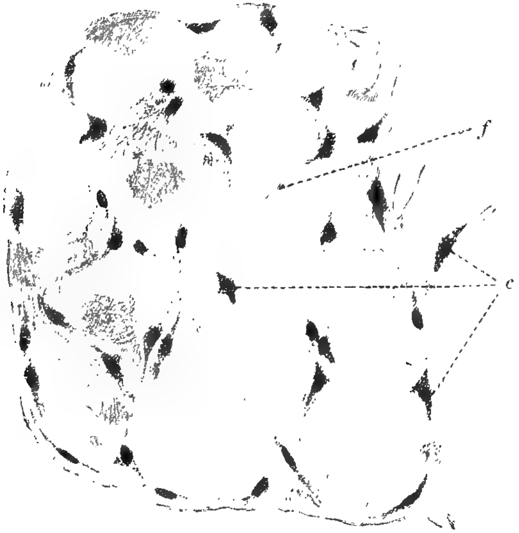

Fig. 130.—Jelly of Wharton from umbilical cord of new-born child. (Sobotta.) × 280.

f, connective-tissue fibres; *c*, cells.

Mall looks upon the intercellular or ground-substance as living substance (*exoplasm*), and as bringing all the cells of the tissue into continuity. He regards the whole structure, cells and ground-substance together, as constituting a continuum, the fibres being laid down by chemical transformation in the exoplasm.

LESSON XI.

THE CONNECTIVE TISSUES (*continued*).

1. Cut two or three thin tangential slices of the fresh cartilage of a joint, mount them in salt solution, and examine with the high power. Observe the form and grouping of the cells. Look at the thin edge of the section for spaces from which the cells have dropped out. Measure two or three cells and their nuclei, and sketch one or two groups. Now replace the salt solution by water and set the preparation aside for a little while. On again examining it, many of the cartilage-cells will be found to have shrunk within their containing capsules.

2. Make other sections of the cartilage (1) from near the middle, (2) from near the edge at the attachment of the synovial membrane. Place the sections for two or three minutes in acetic acid (1 per cent.), wash them with water, and stain with dilute hæmatoxylin solution. When stained mount in dilute glycerine and cement the cover-glass. In (2) look for branched cartilage cells.

3. Study vertical sections of articular cartilage from an end of bone which has been fixed and decalcified, and mount the sections in glycerine and water, or, after staining with hæmatoxylin, in dammar. Sketch the arrangement of the cells in the different layers.

4. Brush a fresh joint with distilled water; drop 1 per cent. nitrate of silver solution over it; after five minutes wash away the nitrate of silver and expose in water to direct sunlight. When browned, place in 90 per cent. alcohol for half an hour or more, and then with a razor wetted with the same spirit cut thin sections from the surface and mount in dammar after passing through clove oil. The cells and cell-spaces show white in the brown ground-substance.

5. To study the structure of synovial membrane mount other slices from the same silvered preparation of the joint (§ 4) taken just beyond the limits of the articular cartilage. Also look for small fringed projections of the membrane. Snip them off with scissors and mount as before.

6. The superficial flexor tendons of the foot of the ox or sheep run in grooves formed by the deep flexors, and these grooves are lined, and the tendons which pass through them are covered by vaginal synovial membranes. To show the structure of these treat one of the superficial flexor-tendons with silver nitrate in the manner recommended for the joint, § 4, and after hardening in 70 per cent. alcohol cut sections from the surface and mount them in dammar as before.

CARTILAGE.

Cartilage (*gristle*) is a translucent bluish-white tissue, firm, and at the same time elastic, and for the most part found in connexion with bones of the skeleton, most of which are in the embryo at first represented entirely by cartilage. Three chief varieties of cartilage are distinguished. In one, which is termed *hyaline*, the matrix or ground-substance is almost clear, and free from obvious fibres; in the other two, which are termed *fibro-cartilage*, the matrix is everywhere pervaded by connective-tissue fibres. When these are of the white variety, the tissue is *white fibro-cartilage*; when they are elastic fibres, it is *yellow* or *elastic fibro-cartilage*.

The matrix immediately around the cartilage-cells is often marked off from the rest by a concentric line or lines, this part of the matrix, which is the latest formed, being known as the *capsule* of the cell. The cells, which lie in groups of two, four, eight, etc., in the matrix are bluntly angular in form, the sides opposite to one another in the groups being generally flattened. The protoplasm is clear, but it may contain droplets of fat; and with a high power fine interlacing filaments and granules have been observed in it. Cartilage-cells also contain, as a rule, glycogen: this can be shown by staining with iodine. During life the protoplasm entirely fills the cavity or cell-space which it occupies in the matrix; but after death, and in consequence of the action of water and some other agents, it tends to shrink away from the capsule. The nucleus is generally spherical and reticular.

The disposition of the cells of cartilage in groups of two, four, eight, etc., is apparently due to the fact that these groups have originated from the division of a single cell first into two, and these again into two, and so on. The division of the cartilage-cell, like that of most other cells, is effected by karyokinesis.

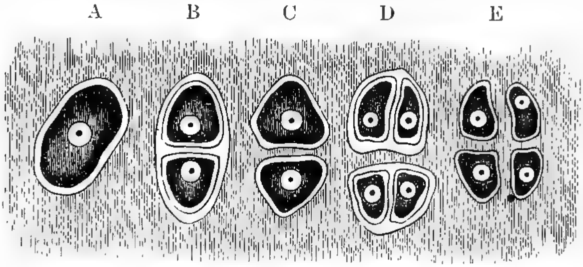

FIG. 131.—PLAN OF THE MULTIPLICATION OF THE CELLS OF CARTILAGE. (Sharpey.)

A, cell in its capsule; *B*, divided into two, each with a capsule; *C*, primary capsule disappeared, secondary capsules coherent with matrix; *D*, tertiary division; *E*, secondary capsules disappeared, tertiary coherent with matrix.

It would seem that the matrix is formed of successive portions, which are deposited around each cartilage-cell as the so-called "capsules" (fig. 131), each newly formed portion soon blending in its turn with the previously formed matrix, whilst a new capsule is formed within it. The most newly formed portions of matrix stain with hæmatoxylin more deeply than the rest, and in some cartilages this gives the appearance of rounded balls of darkly stained matter surrounding each cell or cell-group (*chondrin-balls*, Mörner) (fig. 138).

HYALINE CARTILAGE.

Hyaline cartilage occurs principally in two situations—namely (1) covering the ends of the bones in the joints, where it is known as *articular cartilage*; and (2) forming the rib-cartilages, where it is known as *costal* *cartilage*. It also forms the cartilages of the nose, of the external auditory meatus (but not the pinna), most of those of the larynx, and the cartilages

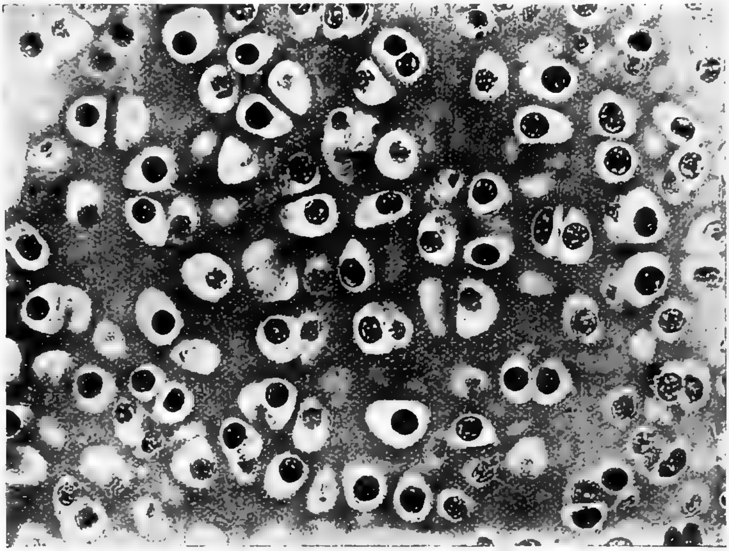

Fig. 132.—Section of hyaline cartilage of salamander. Photograph. Magnified 200 diameters.

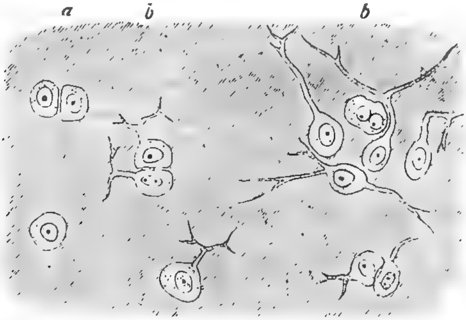

Fig. 133.—Border of articular cartilage showing transition of cartilage-cells into connective-tissue corpuscles of synovial membrane. From head of metatarsal bone, human. About 340 diameters.

a, ordinary cartilage-cells; *b*, *b*, with branching processes.

of the windpipe; in these places it serves to maintain the shape and patency of the orifices and tubes.

By long maceration in brine, evidence of a fibrous structure may be obtained, even in the matrix of true hyaline cartilage. Some histologists have described fine communications in the matrix uniting the cartilage-cells

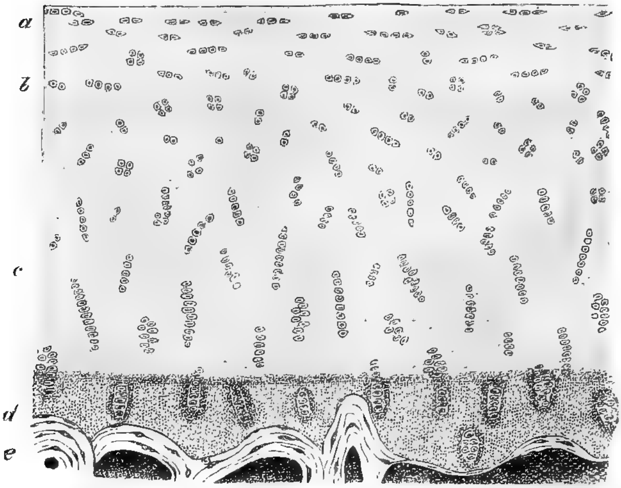

FIG. 134.—VERTICAL SECTION OF ARTICULAR CARTILAGE COVERING THE LOWER END OF THE TIBIA, HUMAN. Magnified about 30 diameters.

a, cells and cell-groups flattened conformably with the surface ; b, cell-groups irregularly arranged ; c, cell-groups disposed perpendicularly to the surface ; d, layer of calcified cartilage ; e, bone.

with one another, but these are of doubtful occurrence in vertebrate cartilage, although they unquestionably exist in the cartilage of cephalopods.

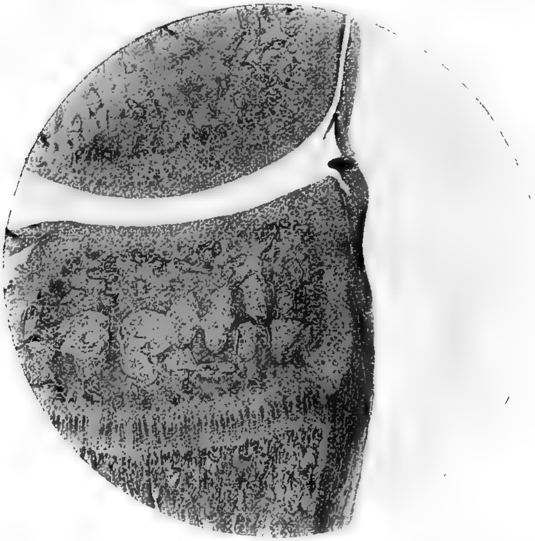

FIG. 135.—SECTION OF JOINT OF YOUNG RABBIT. Magnified 50 diameters.

Notice the capsular ligament uniting the ends of the bones and lined by the thin synovial membrane in which there are folds projecting slightly into the edge of the joint.

Articular cartilage and synovial membrane.—The cells of articular cartilage are generally scattered in elongated groups throughout the matrix (fig. 134). The latter is free from obvious fibres, except at the extreme edge of the cartilage, where the connective-tissue fibres from the synovial membrane extend into it; and here also the cartilage-cells are often branched, and offer transitions to the branched connective-tissue corpuscles of that membrane (*transitional cartilage*, fig. 132).

In vertical section (fig. 134) the deeper cell groups (*c*) are seen to be arranged vertically to the surface, the more superficial ones (*a*) parallel to the surface; whilst in an intermediate zone the groups are irregularly disposed (*b*). In the deepest part of the cartilage, next to the bone, there is often a deposit of calcareous salts in the matrix (*calcified cartilage*, *d*).

Synovial membranes are connective-tissue structures occurring in connexion with articular cartilage (fig. 135) and in certain other movable parts, *e.g.* where a tendon glides within a fibrous sheath, and at the so-called bursæ, such as that which lies between the skin and the patella. Their cells are for the most part branched like connective-tissue cells, but in some places they resemble cartilage-cells, and where a synovial membrane is continuous with cartilage, transitions occur between them.

The synovial membranes are often compared with serous membranes. Like the latter they bound closed cavities moistened with fluid, but they are not connected with the lymphatic system, nor is the fluid (synovia) which moistens them of the nature of lymph. Moreover, there is either no endothelial lining, or it occurs only in patches, in place of the continuous lining which we find in serous membranes. Long villus-like projections, simple (fig. 136) or compound—the so-called *Haversian fringes*—occur in some situations; they are beset in parts by cells, some of which appear to be cartilage-cells and to be surrounded by cartilage-matrix. The fringes probably serve to extend the surface for the secretion of synovia. The blood-vessels of synovial membranes are numerous; they approach close to the inner surface. They are well seen in preparations from an injected limb.

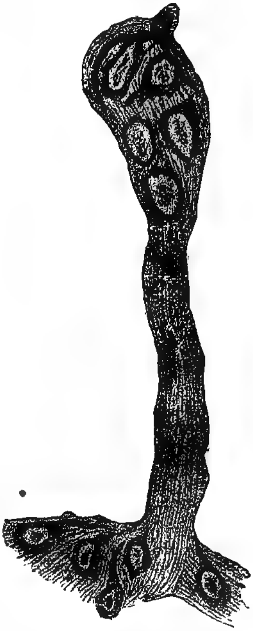
FIG. 136.—VILLUS OF SYNOVIAL MEMBRANE. (Hammar.)

Besides the Haversian fringes and villi there are often larger folds of the membrane containing fat.

The synovial membrane of a joint is never prolonged over the opposed surfaces of the articular cartilages, but ceases near the edge of these in the transitional zone already alluded to. The blood-vessels of the membrane terminate here in capillary loops. The nerves of synovial membranes end partly in peculiar end-bulbs in the substance of the membrane, partly in a fine terminal plexus close to the inner surface. Pacinian corpuscles have also been described in some places.

LESSON XII.

THE CONNECTIVE TISSUES (*continued*).

1. MAKE transverse and tangential sections of a rib-cartilage (calf or lamb) which may either be fresh, or may have been preserved in spirit or formol. Stain the sections with hæmatoxylin or carmalum (if fresh, after treatment with acetic acid as in Lesson XI. § 2; or they may be placed for an hour in ·5 per cent. osmic acid), and mount in glycerine. Sketch a part of a transverse section under a low power and a cell-group from one of the tangential sections under a high power. Notice especially the arrangement of the cells, somewhat concentric near the surface but radial near the centre. The costal cartilages tend as age advances to become ossified; near the middle of their thickness in most animals; but in man when ossification occurs it is the superficial layer which is first invaded.

2. Make sections of the cartilage of the external ear (pinna), either fresh or after hardening in alcohol. Mount in dilute glycerine faintly coloured with magenta or stain with orcein and mount in dammar. The upper end of the arytenoid cartilage of the ox or calf may also be used to display the structure of elastic cartilage. Notice the large reticulating elastic fibres in the matrix. Notice also the isolated granules of elastin, and around each cartilage-cell an area of clear ground-substance. If the preparation be from the ear of the mouse or rat there is very little matrix and no elastic fibres, and the cells are almost in contact (parenchymatous cartilage).

3. Mount a section of the epiglottis in the same way. Notice the closer network of much finer elastic fibres in its cartilage.

4. Cut sections of white fibro-cartilage (intervertebral disk or semilunar cartilage of knee), which has been hardened in picric acid followed by spirit, or in spirit only. Stain the sections with dilute hæmatoxylin or carmalum. Mount in dilute glycerine. Observe the wavy fibres in the matrix and the cartilage-cells, sometimes branched, lying in clear areas often concentrically striated. Sketch three or four cells and the adjoining fibrous matrix.

HYALINE CARTILAGE (*continued*).

Costal cartilage.—In the rib-cartilages (fig. 137) the matrix is not always as clear as in the cartilages of the joints, for it more often happens that fibres become developed in it. The cells are generally larger than those of articular cartilage, and collected into larger groups (fig. 138). Near the circumference, and under the perichondrium or fibrous covering of the cartilage, they are flattened and parallel to the surface, but in the deeper parts they have a more irregular or a radiated arrangement. They frequently contain fat. The cartilages of the larynx and windpipe and of the nose resemble on the whole the costal cartilages, but the study of them may be deferred until the organs where they occur are dealt with.

YELLOW FIBRO-CARTILAGE.

Elastic or yellow fibro-cartilage occurs in only a few situations, viz. :—the cartilage of the external ear, that of the Eustachian tube, and the epiglottis and cartilages of Santorini of the larynx. The matrix is everywhere pervaded except immediately around the cells and cell-groups with well-defined branching fibres, which unite with one another to form a close

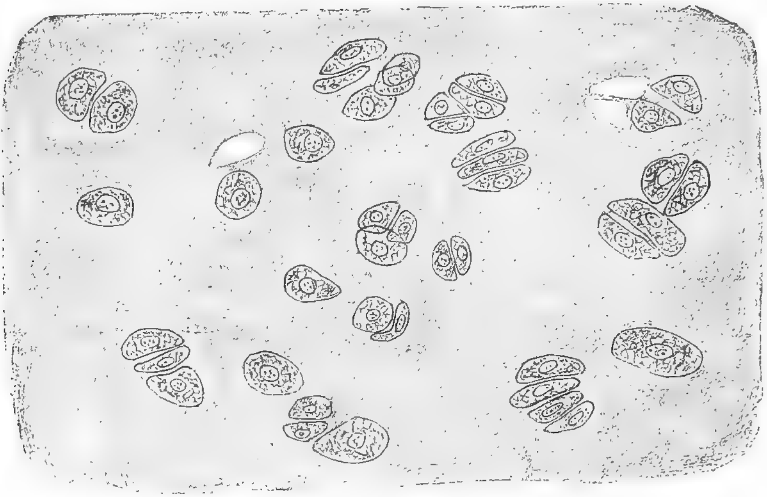

FIG. 137.—SECTION OF RIB-CARTILAGE OF CALF. High power.

The matrix is indistinctly fibrous. Two or three empty cell-spaces are seen in the section, the cells having dropped out in the course of preparation.

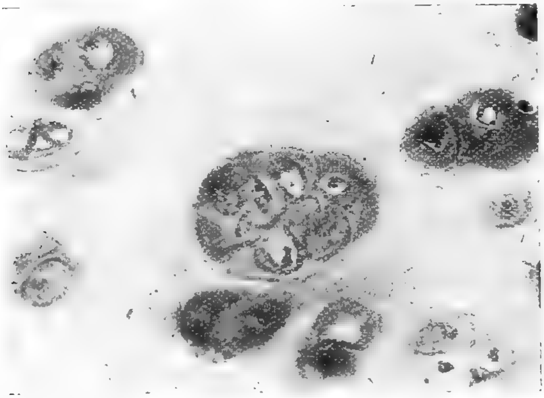

FIG. 138. SECTION OF COSTAL CARTILAGE. Photograph. Magnified 240 diameters.

The section shows several groups of cartilage-cells. Capsule outlines are seen around the groups and also around the individual cells. The part around the cells and cell-groups is stained more than the rest of the matrix.

network (fig. 139). These fibres resist the action of acetic acid, and are stained deeply by magenta and orcein; they are evidently elastic fibres. In

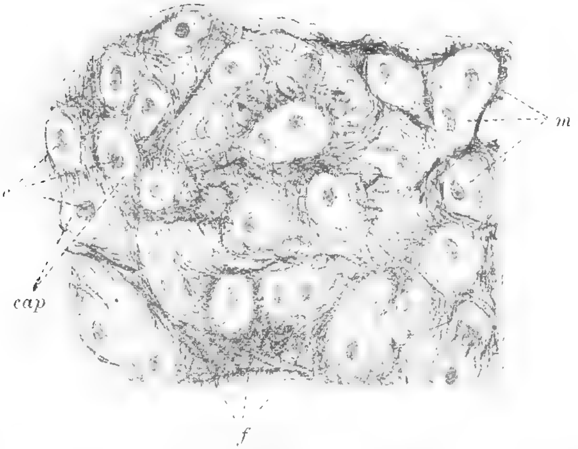

FIG. 139.—SECTION OF ELASTIC CARTILAGE OF EAR, HUMAN. (Sobotta.) × 280.
c, cartilage-cells; *cap*, their capsules; *m*, clear matrix around cells and cell-groups; *f*, elastic fibres.

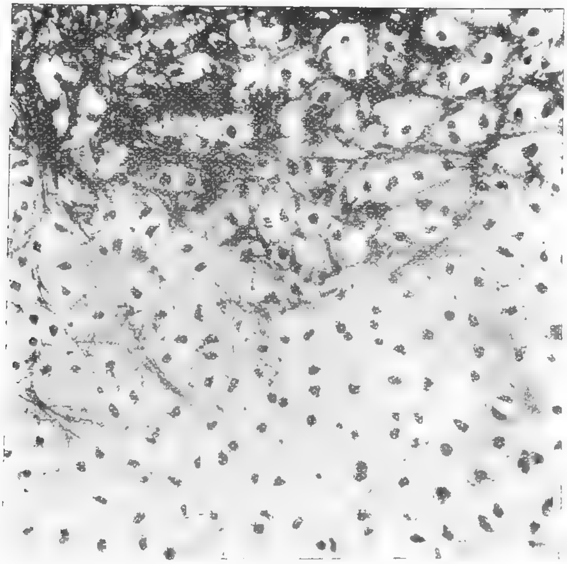

FIG. 140.—SECTION OF ARYTENOID CARTILAGE OF CALF AT JUNCTION OF HYALINE WITH ELASTIC PORTIONS. Magnified 50 diameters.

the ox they are very large, but smaller in man, especially in the cartilage of the epiglottis. They appear to be developed, as with elastic tissue elsewhere (see p. 97), by the deposition of granules of elastin in the matrix (fig. 141); the granules at first lie scattered, but afterwards become joined to form fibres.

WHITE FIBRO-CARTILAGE.

White fibro-cartilage is found wherever great strength combined with a certain amount of rigidity is required: thus we frequently find this form of fibro-cartilage joining bones together, as in the intervertebral disks and other symphyses. But in these cases the part in contact with the bone is always hyaline cartilage, which passes gradually into the fibro-cartilage forming the bulk of the symphysis. White fibro-cartilage is also found lining grooves in which tendons run, and it may be found in the tendons themselves. It is employed to deepen cup-shaped articular surfaces; and in the case of the interarticular cartilages, such as those of the knee and lower jaw, to allow greater freedom of movement whilst diminishing the liability to dislocation. Under the microscope white fibro-cartilage looks very like fibrous tissue, but its cells are cartilage-cells, not tendon-cells (figs. 142, 143). They are rounded or bluntly angular and surrounded by a concentrically striated area of clear cartilage-matrix. In some parts of the intervertebral disk many of the cells are branched, and may be looked upon as transitional forms to connective-tissue corpuscles.

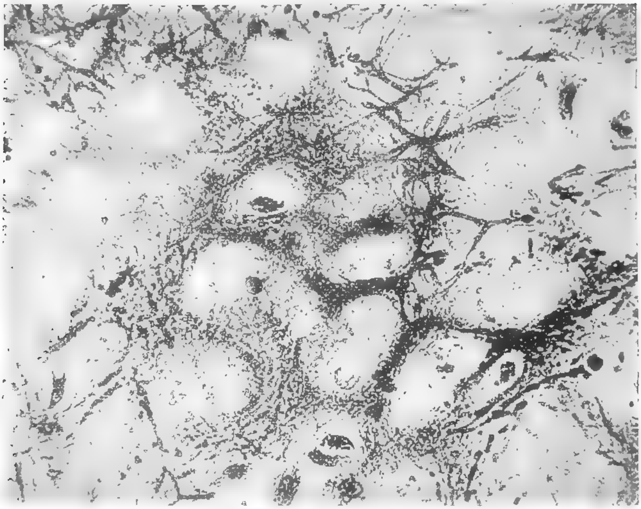

FIG. 141.—SECTION OF ELASTIC CARTILAGE (UPPER PART OF ARYTENOID OF CALF) STAINED WITH MAGENTA. Photograph. Magnified 200 diameters.

The elastin is seen partly in the form of a granular deposit, partly as finer and coarser intercommunicating fibres. These are nowhere in contact with the cartilage-cells, which are surrounded by clear cartilage-matrix. At most parts of the section the cells have dropped out, but two or three are seen still *in situ*.

DEVELOPMENT OF CARTILAGE.

Cartilage is formed in the embryo from mesenchyme similar to that which gives origin to other forms of connective tissue. Each cell forms a capsule around itself, and the blended capsules compose the first matrix.

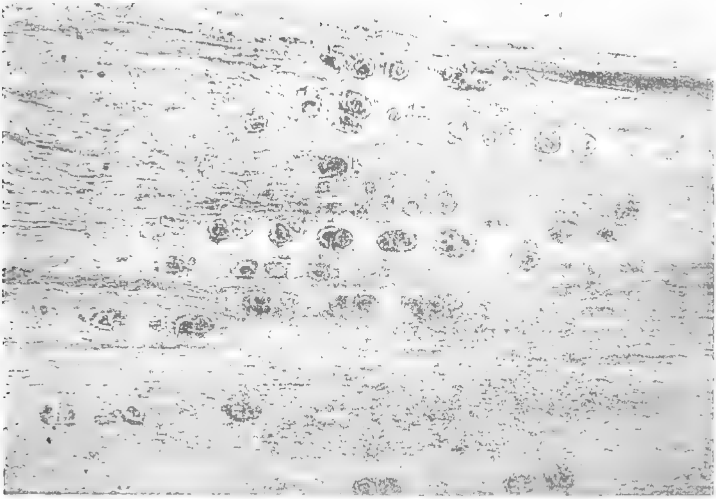

FIG. 142.—SECTION OF WHITE FIBRO-CARTILAGE. Photograph. Magnified 200 diameters.

The ground-substance is pervaded by wavy connective-tissue fibres.

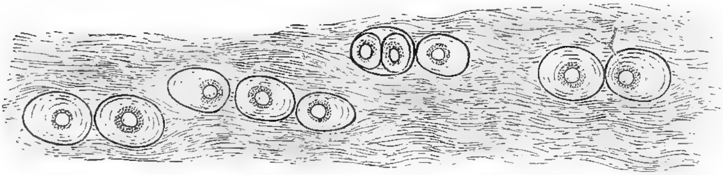

FIG. 143.—WHITE FIBRO-CARTILAGE FROM AN INTERVERTEBRAL DISK, HUMAN. Highly magnified.

The concentric lines around the cells indicate the limits of deposit of successive capsules. One of the cells has a forked process which extends beyond the hyaline area surrounding the cell, amongst the fibres of the general matrix.

Cartilage sometimes remains in this condition throughout life; it is then termed *parenchymatous cartilage.* This can be seen in the mouse's ear; where also the cartilage-cells become filled with fat. Cartilage at first grows partly by interstitial expansion (accompanied by cell multiplication and by formation around and between the cells of intercellular substance), partly by apposition at the perichondrium, the connective tissue becoming here transformed into cartilage. At a later period of growth the increase in size and change in shape of cartilages are due almost entirely to the agency of the perichondrium.

Embryonic cartilage is usually characterised by the cells being more sharply angular and irregular; in some cases they are branched, like those which occur at the junction of cartilage and synovial membrane in the adult. The cells are also more closely packed, the matrix being in relatively less amount than in later life.

Fibro-cartilage is developed at first in exactly the same manner as hyaline cartilage, but at a certain stage connective-tissue fibres, either elastic or white, become formed in the ground-substance or matrix, and as they accumulate they impart their distinctive character to the tissue.

In some parts where white fibro-cartilage is found there is reason to believe that the tissue is at first entirely fibrous, like tendon or ligament, and that the cartilage is a secondary formation. In such cases the cartilage-cells are probably formed by a direct transformation from the tendon-cells.

LESSON XIII.

THE CONNECTIVE TISSUES (*continued*).

1. In thin sections of hard bone made by grinding,[1] observe the Haversian canals, lamellæ, lacunæ, canaliculi, etc. Make sketches under low and high powers.

2. With fine forceps strip off a thin shred from the superficial layers of a bone which has been decalcified in 5 per cent. commercial sulphurous acid and afterwards washed with water for 24 hours. The decalcified bone may be kept in dilute alcohol. Mount the shred in water. Observe the fibrous structure of the lamellæ. Look for perforating fibres or the holes from which they have been dragged out. Sketch a small piece of the thin edge of a lamella.

3. Stain successively with dilute magenta and hæmatoxylin solution, or with methyl-blue and eosin, very thin sections of compact bone which has been fixed with 10 per cent. formol (1 to 3 days) and then decalcified in sulphurous acid as above. Mount in dilute glycerine, cementing at once. Look for fibres of Sharpey piercing the circumferential lamellæ. The elastic perforating fibres are more darkly stained than the others. Notice the stained nuclei of the bone-corpuscles in the lacunæ. In thin sections the blood-vessels and other structures in the Haversian canals may be made out.

4. Mount in dammar a section of a fœtal lower jaw which has been stained in bulk and embedded in paraffin.[2] Find the part where the lower jaw-bone is becoming ossified, and carefully study the appearance which it presents. The bone is prolonged in the form of osteogenic fibres which are covered with osteoblasts.

5. Intramembranous ossification may also be studied in the parietal bone of a fœtus which has been preserved in Müller's fluid. A piece of the growing edge is scraped or brushed free from its investing membranes, and from most of the cells which cover and conceal it, and is mounted in glycerine with or without previous staining with carmalum.

6. Mount in dammar sections of a fœtal limb which has been stained in bulk. The bones will be found in different stages of ossification, those of the digits being least developed. Make sketches illustrating the three chief stages of endochondral ossification. Notice the peculiar terminal ossification of the third phalanx.

BONE; STRUCTURE AND DEVELOPMENT.

Bone is a connective tissue in which the ground-substance is impregnated with salts of lime, chiefly phosphate, these salts constituting about two-thirds of the weight of the bone. When bones are macerated this earthy matter prevents the putrefaction of the animal matter. When bones are calcined they lose one-third of their weight, owing to the destruction of the animal matter; when steeped in acid the earthy salts are dissolved and only the animal matter is left. This, like areolar and fibrous tissue, is converted into gelatin by boiling.

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[1] Such a section should be purchased.

[2] See Appendix for method of staining in bulk. In place of this the sections may be stained by Mallory's method, which brings out the osteogenic fibres.

Bony tissue is either *compact* or *cancellated.* Compact bone is dense, like ivory; cancellated is spongy with obvious interstices. The outer layers of all bones are compact, and the inner part is generally cancellated, but the shaft of a long bone is almost entirely made up of compact substance, except along the middle, which is hollow and filled with marrow. The

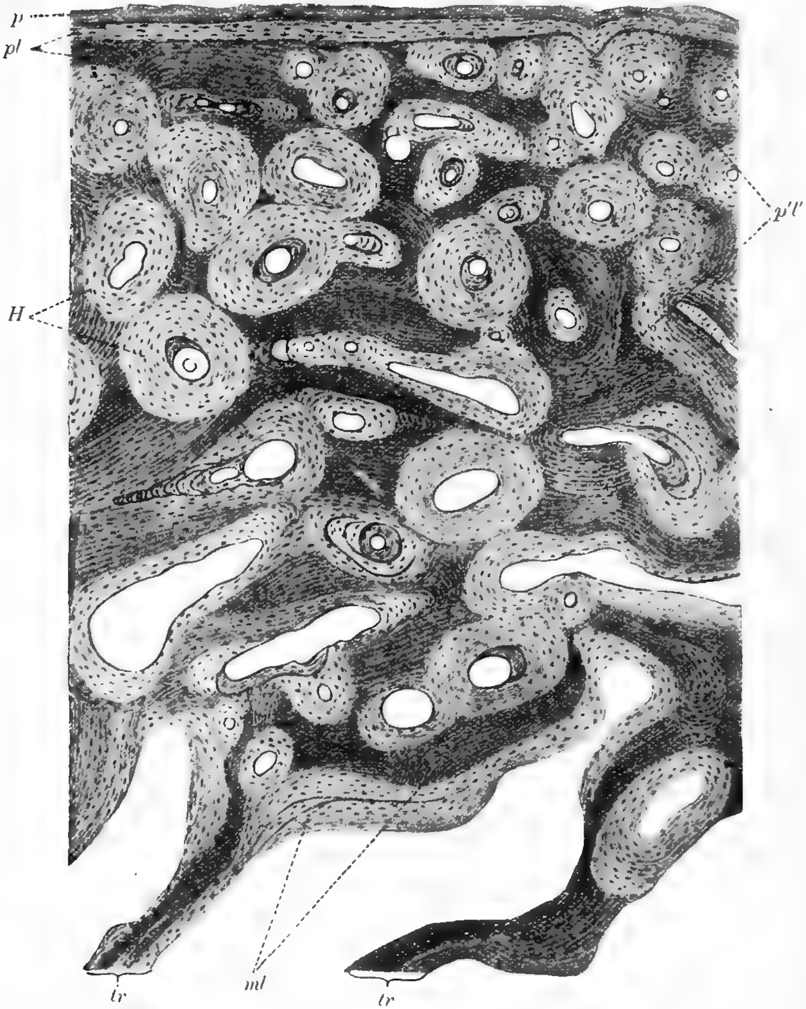

FIG. 144.—SECTION OF A DECALCIFIED HUMAN RADIUS. (Sobotta.) × 48.

p, periosteum; *pl*, periosteal bony lamellæ; *p'l'*, deeply seated lamellæ between the Haversian systems; ***H***, Haversian systems; *tr*, *tr*, trabeculæ of spongy substance; *ml*, lamellæ bounding medullary spaces.

interstices of cancellated bone are also occupied by marrow. Externally bones are covered except at the joints by a vascular fibrous membrane, the *periosteum*.

True bone is always made up of *lamellæ*, and these again are composed of fine *fibres* lying in a *calcified ground-substance*. Between the lamellæ are branched cells, the *bone-corpuscles*, which lie in cell-spaces or *lacunæ*. The ramified passages which contain the cell-processes and unite the lacunæ are termed *canaliculi*.

In cancellated bone the blood-vessels run in the interstices of the bone, surrounded and supported by the marrow. In compact bone they are contained in little canals—the *Haversian canals*—which everywhere pervade the bone. These canals are about 0·05 mm. ($\frac{1}{500}$ inch) in diameter, but some are smaller, others larger than this. Their general direction is longitudinal, *i.e.* parallel to the long axis of the bone, but they are constantly united by transversely and obliquely running passages. In a section across the shaft of a long bone they are seen as small rounded or oval holes (fig. 144). When the section has been made by grinding, the holes get filled up with air and débris, and they then look black by transmitted light, as do also the lacunæ and canaliculi (fig. 145). Most of the lamellæ in

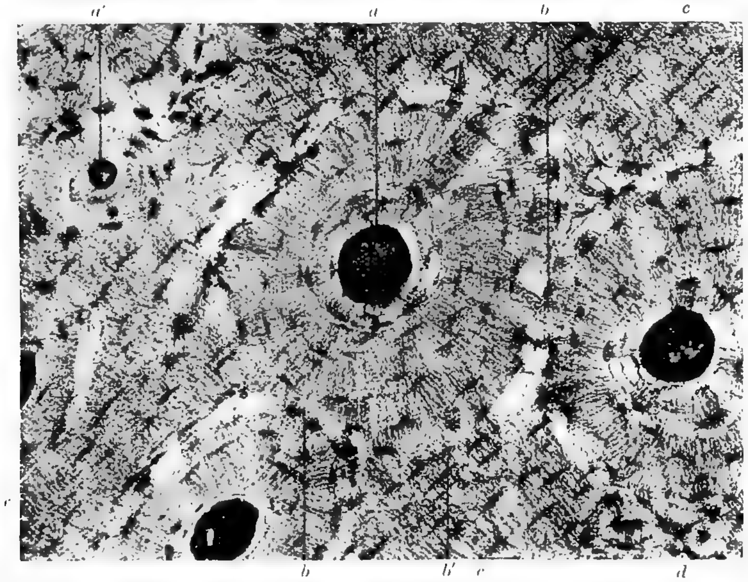

FIG. 145.—PHOTOGRAPH OF TRANSVERSE SECTION OF COMPACT BONE, MADE BY GRINDING, SHOWING THREE HAVERSIAN CANALS WITH THEIR CONCENTRIC LAMELLÆ, AND ALSO INTER-HAVERSIAN BONY SUBSTANCE. Magnified 200 diameters.

a, Haversian canal, filled with air and débris; *a′*, a very small canal; *b*, *b*, junction of two Haversian systems; *b′*, margin of Haversian system abutting on inter-Haversian lamellæ; *c*, *c*, *c*, lamellæ parallel to periosteum; *d*, inter-Haversian bone with irregular lacunæ.

compact bone are disposed concentrically around the Haversian canals; they are known as the Haversian lamellæ, and with the included canal, form what is known as a *Haversian system.* The lacunæ of a Haversian system communicate with one another and with the Haversian canal, but not as a rule with the lacunæ of adjacent Haversian systems. The angular interstices between the Haversian systems are generally occupied by bony substance which is not regularly lamellar (figs. 145, 146, *d*). Besides the lamellæ of the Haversian systems there is a certain thickness of bone at the surface, immediately underneath the periosteum, which is composed of lamellæ arranged parallel with the surface; these are the *periosteal lamellæ* (fig. 144, *pl*). They are pierced here and there by simple canals for blood-vessels, the so-called *Volkmann's canals*, which are proceeding from the periosteum to join the system of Haversian canals, and by calcified bundles of white fibres and by elastic fibres which may also be prolonged from the periosteum. These are the *perforating fibres of Sharpey* (fig. 147).

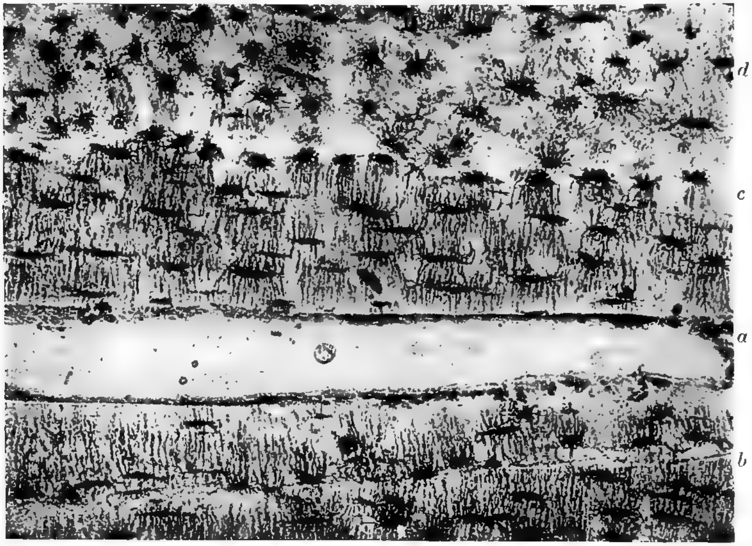

FIG. 146.—LONGITUDINAL SECTION OF COMPACT BONE, SHOWING HAVERSIAN SYSTEMS OF LAMELLÆ, AND INTER-HAVERSIAN BONE. Magnified 200 diameters.

a, Haversian canal cut longitudinally; *b*, junction of two Haversian systems of lamellæ; *c*, margin of Haversian system abutting upon inter-Haversian bone with irregular lacunæ, *d*.

The lamellæ of bone are fibrous in structure. This may be seen in shreds torn off from the superficial layers of a decalcified bone. The fibres (*decussating fibres of Sharpey, lamella-fibres*) often cross one another in adjacent lamellæ, and in the Haversian systems they run in some lamellæ concentrically, in others parallel with the Haversian canal. In shreds of lamellæ which have been peeled off from the surface the perforating fibres

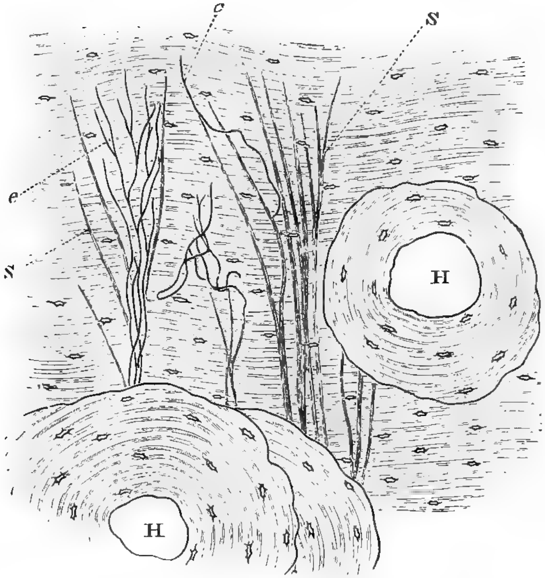

FIG. 147.—TRANSVERSE SECTION OF DECALCIFIED HUMAN TIBIA, FROM NEAR THE SURFACE OF THE SHAFT.

H, H, Haversian canals, with their systems of concentric lamellæ; in all the rest of the figure the lamellæ are periosteal; *s*, *s*, ordinary perforating fibres of Sharpey; *e*, *e*, elastic perforating fibres. Drawn under a power of about 150 diameters.

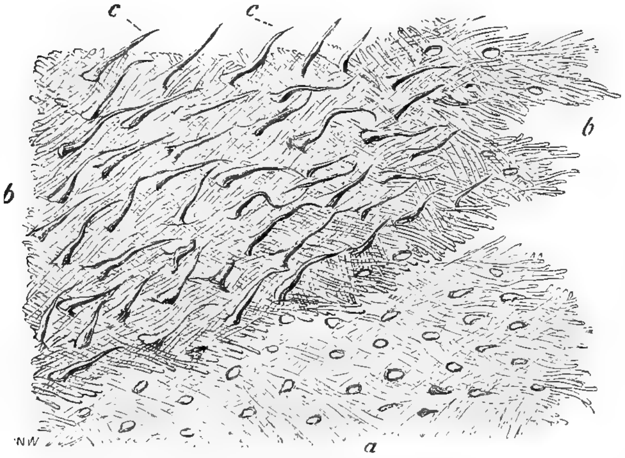

FIG. 148.—LAMELLÆ TORN OFF FROM A DECALCIFIED HUMAN PARIETAL BONE AT SOME DEPTH FROM THE SURFACE.

a, lamellæ, showing decussating fibres; *b*, *b*, thicker part, where several lamellæ are superposed; *c*, *c*, perforating fibres; the fibrils which compose them are not shown in the figure. Apertures through which perforating fibres had passed are seen, especially in the lower part, *a*, of the figure. Magnitude as seen under a power of 200 diameters, but not drawn to scale. (Sketched by Allen Thomson from a preparation by W. Sharpey.)

may sometimes be seen projecting from the surface of the shred, having been torn out of the deeper lamellæ (fig. 148, *c*, *c*). When tendons or ligaments are inserted into bone, their bundles of white fibres are prolonged into the bone as perforating fibres.

The lacunæ are occupied by nucleated corpuscles, which send branches along the canaliculi (fig. 149). They have a special lining layer different in chemical composition from the rest of the bone, being much more resistant to the action of strong chemical solvents such as hydrochloric acid (Neumann). The dentinal tubules of the teeth have a similar lining layer.

The Haversian canals contain one or two blood-capillaries and nervous filaments, besides a little connective tissue; the larger ones may include a few marrow-cells. There are also cleft-like lymphatics running with the blood-vessels, their cells being connected through canaliculi with branches from corpuscles within the neighbouring lacunæ of the osseous substance (fig. 150).

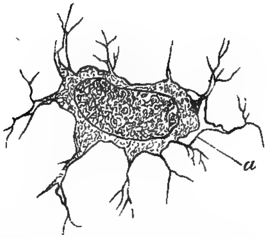

FIG. 149.—A BONE-CELL ISOLATED AND HIGHLY MAGNIFIED. (Joseph.)

a, proper wall of the lacuna (Neumann's layer), where the corpuscle has shrunken away from it.

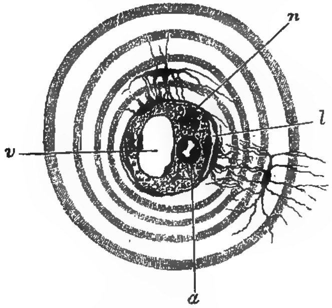

FIG. 150.—SECTION OF A HAVERSIAN CANAL, SHOWING ITS CONTENTS. Highly magnified.

a, small arterial capillary vessel; *v*, large venous capillary; *n*, pale nerve fibres cut across; *l*, cleft-like lymphatic vessel; one of the cells forming its wall communicates by fine branches with the branches of a bone-corpuscle. The substance in which the vessels run is connective tissue with ramified cells; its finely granular appearance is probably due to the cross-section of fibrils. The canal is surrounded by several concentric lamellæ.

The **periosteum** may be studied in torn-off shreds, in preparations stained *in situ* with silver nitrate, and in stained sections from an unmacerated bone which has been decalcified. It is a fibrous membrane composed of two layers, the inner of which contains many elastic fibres. In the outer layer numerous blood-vessels ramify and send branches to the Haversian canals of the bone. The periosteum ministers to the nutrition of the bone, partly on account of the blood-vessels and lymphatics it contains, partly, especially in young animals, on account of the existence between it and the bone of a layer of *osteoblasts* or *bone-forming cells*, a remainder of those which originally produced the bone. It also serves to give attachment to muscular fibres.

The **marrow** of bone has been already studied (pp. 45 to 47).

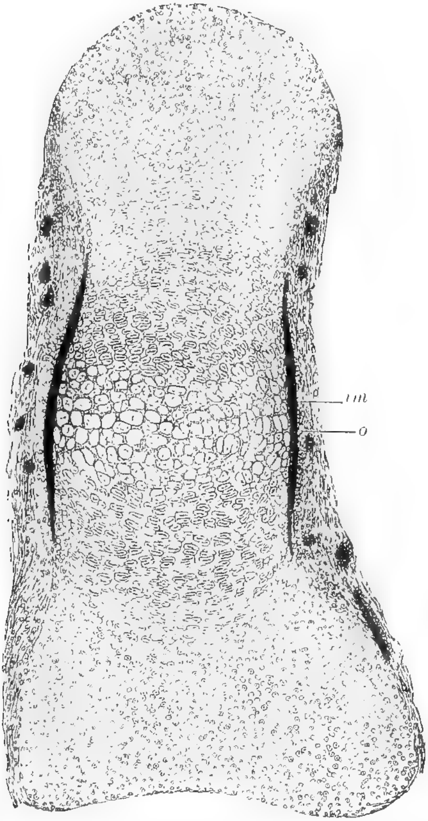

FIG. 151.—SECTION OF PHALANGEAL BONE OF HUMAN FŒTUS AT THE TIME OF COMMENCING OSSIFICATION. (From a preparation by Dr F. A. Dixey.) The preparation was stained in bulk with magenta. The drawing is made from a photograph, and is magnified about 75 diameters.

The cartilage-cells in the centre are enlarged and are separated from one another by stained calcified matrix; *im*, layer of bone deposited underneath the periosteum; *o*, layer of osteoblasts by which the layer has been formed. Some of the osteoblasts are already embedded in the new bone as bone-cells within lacunæ. The cartilage-cells are flattened and arranged in rows above and below the calcified centre. At the ends of the cartilage the cells are small and the groups are irregularly arranged; the fibrous periosteum is not sharply marked off from the cartilage.

DEVELOPMENT OF BONE.

True bone is formed in all cases by ossification of connective tissue. Sometimes the bone is preceded by cartilage, which first becomes calcified, and this is then invaded, and for the most part removed, by an embryonic connective tissue which re-deposits bony matter in the interior of the cartilage. This is *intracartilaginous* or *endochondral ossification.* At the same time layers of bone are being developed outside the cartilage underneath the periosteum. The whole bone thus formed is termed a *cartilage-bone.* Sometimes the bone is not preceded by cartilage, and then the only process which occurs is one corresponding to the subperiosteal ossification of the cartilage bone; the ossification is then known as *intramembranous*, and the bone formed is a *membrane-bone.*

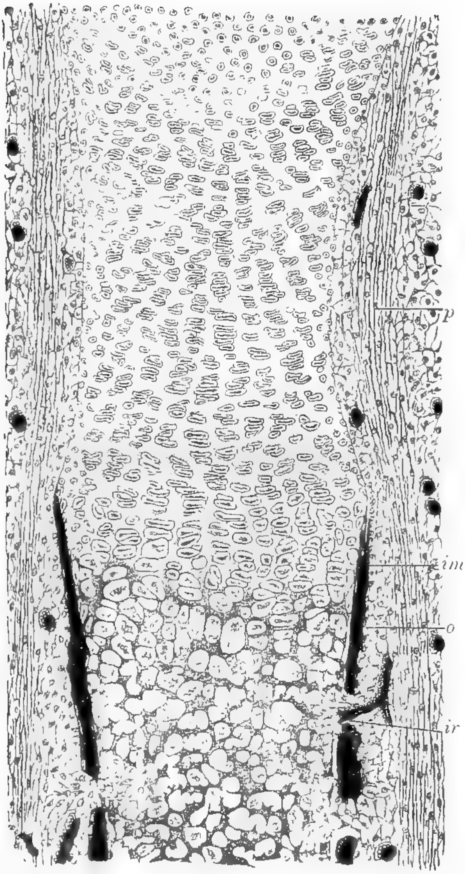

FIG. 152.—SECTION OF PART OF ONE OF THE LIMB-BONES OF A FŒTAL CAT, AT A MORE ADVANCED STAGE OF OSSIFICATION THAN THE BONE REPRESENTED IN FIG. 151, AND MORE HIGHLY MAGNIFIED. Drawn from a photograph.

The calcification of the cartilage-matrix has advanced from the centre, and is extending between the groups of cartilage-cells, which are arranged in characteristic rows. The subperiosteal bony deposit (*im*) has extended *pari passu* with the calcification of the cartilage-matrix. The cartilage-cells in the calcified part are mostly shrunken and stellate; in some cases they have dropped out of the spaces. At *ir* and in two other places an irruption of the subperiosteal tissue, composed of ramified cells with osteoblasts and growing blood-vessels, has penetrated the subperiosteal bony crust, and has begun to excavate medullary spaces; *p*, fibrous layer of the periosteum; *o*, layer of osteoblasts: some of them are embedded in the osseous layer as bone-corpuscles in lacunæ. The blood-vessels are occupied by blood-corpuscles. Beyond the line of ossific advance the periosteum may be noticed to be incurved. This incurvation is gradually moved on, the cartilage expanding behind it until the head of the bone is reached, when it forms the periosteal notch or groove represented in figs. 155 and 159.

Ossification in cartilage.—This may be described as occurring in three stages.

In the *first stage* the cells in the middle of the cartilage become enlarged and arranged in rows radiating from the centre (fig. 151), and fine granules of calcareous matter are deposited in the matrix. Simultaneously with this the osteoblasts underneath the periosteum deposit a layer or layers of fibrous material upon the surface of the cartilage, and this material also becomes calcified (fig. 151, *im*). As the layers are formed, some of the osteoblasts (*o*) are included between them and become bone-corpuscles.

In the *second stage* the vascular subperiosteal tissue eats its way through the newly formed layer of bone and into the centre of the calcified cartilage (fig. 152, *ir*). This is freely absorbed before it (figs. 153, 154), so that large spaces are produced which are occupied by embryonic connective tissue of a jelly-like character (fig. 158) including numerous osteoblasts and many sinus-like blood-vessels which have grown in from those of the periosteum. The spaces are termed *marrow or medullary spaces*, and this second stage is known as the *stage of irruption*.

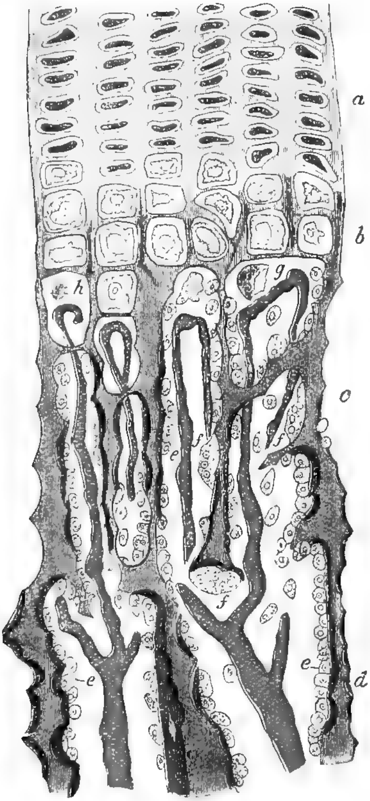

Fig. 153.—Part of a longitudinal section of the developing femur of the rabbit. (Klein.) Drawn under a magnifying power of 350 diameters.

a, rows of flattened cartilage-cells; *b*, greatly enlarged cartilage-cells close to the advancing bone, the matrix between is partly calcified; *c*, *d*, already formed bone, the osseous trabeculæ being covered with osteoblasts (*e*) except here and there, where an osteoclast (*f*) is seen eroding parts of the trabeculæ; *g*, *h*, cartilage-cells which have become shrunken and irregular in shape. From the middle of the figure downwards the trabeculæ, which are formed of calcified cartilage-matrix, are becoming covered with secondary osseous substance deposited by the osteoblasts. The vascular loops at the extreme limit of the bone are well shown, as well as the atrophy and abrupt disappearance of the cartilage-cells.

In the *third stage* of endochondral ossification there is a gradual advance of the ossification towards the extremities of the cartilage, and at the same time a gradual deposition of fresh bony layers on the walls or septa of the medullary spaces, and on the surface of the new bone under the periosteum (figs. 153, 157, 158). The advance into the cartilage always takes place by a repetition of the same changes, the cartilage-cells first enlarging and becoming arranged in rows, the matrix between the rows becoming calcified, and then the calcified cartilage becoming excavated from behind by the osteoblastic tissue so as to form new medullary spaces (fig. 153). The septa between these are at first formed only by remains of the calcified cartilage-matrix (fig. 153, *c*), but they soon become thickened by layers of fibrous bone which is deposited by the osteoblasts (fig. 158), and between the layers bone-corpuscles become included, as in the case of the subperiosteal bone. The latter advances *pari passu* with the endochondral calcification, growing both in length and thickness: its growth is preceded by the formation of osteogenic fibres like those met with in developing membrane bone (see p. 124). Beyond the line of advance of ossification the uncalcified cartilage grows by expansion both in length and breadth, so that the ossification is always advancing into a larger mass of cartilage; hence the endochondral bone as it forms assumes the shape of an hour-glass, the shaft being maintained of a cylindrical shape by addition of periosteal bone to the

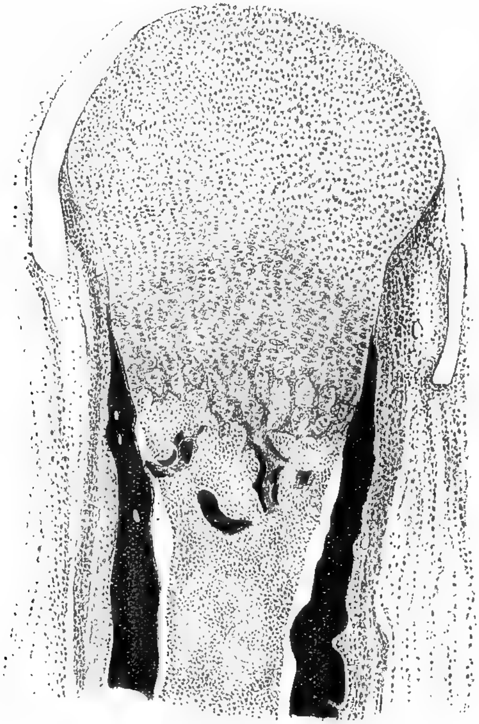

FIG. 154.—LONGITUDINAL SECTION THROUGH PART OF A PHALANX OF A SIX MONTHS' HUMAN EMBRYO. (Kölliker.)

The calcified cartilage is completely absorbed almost to the limit of advancing calcification. The osseous substance on either side is periosteal bone. The embryonic marrow has shrunk somewhat away from it in the process of fixation.

outside, this addition being of course always thickest in the middle of the shaft (see fig. 155). The absorption of the calcified cartilage matrix appears to

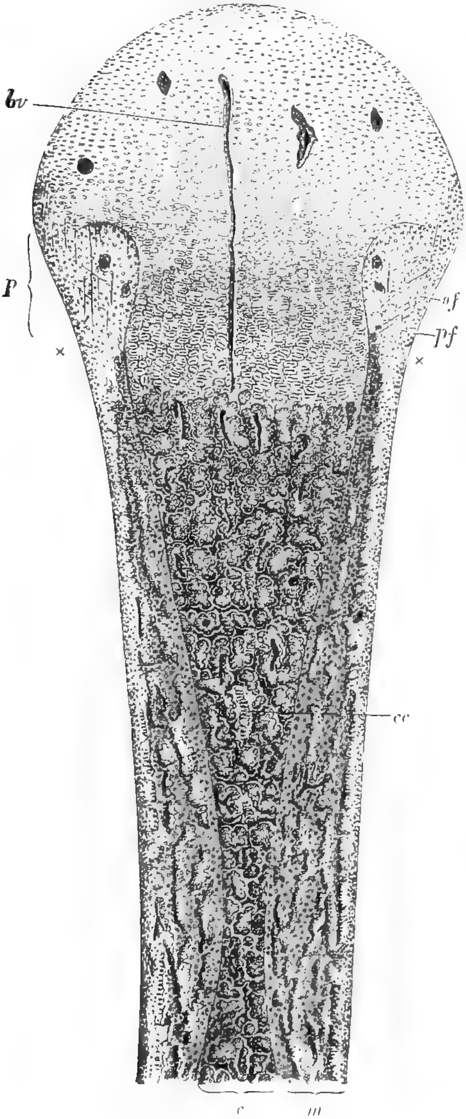

FIG. 155.—LONGITUDINAL SECTION THROUGH THE UPPER HALF OF THE DECALCIFIED HUMERUS OF A FŒTAL SHEEP, AS SEEN UNDER A MAGNIFYING POWER OF ABOUT 30 DIAMETERS.

c, the part of the shaft which was primarily ossified in cartilage; what remains of the primary bone is represented dark, enveloped by the clear secondary deposit. The areolæ of the bone are occupied by embryonic marrow with osteoblasts, and blood-vessels variously cut. One long straight vessel (*bv*) passes in advance of the line of ossification far into the cartilaginous head, most of the others loop round close to the cartilage. At one or two places in the older parts of the bone elongated groups of cartilage-cells (*cc*) may still be seen, which have hitherto escaped absorption. *m*, the part of the bone that has been ossified in membrane, that is to say, in the osteoblastic tissue under the periosteum. It is well marked off from the central portion (*c*), and is bounded, peripherally, by a jagged edge, the projections of which are indistinctly seen to be prolonged by bunches of osteogenic fibres. A row of oteoblasts covers the superficial layer of the bone. The subperiosteal layer is prolonged above into the thickening (*p*) which encroaches upon the cartilage of the head of the bone, and in which are seen amongst numerous osteoblasts and a few blood-vessels, the straight longitudinal osteogenic fibres (*of*), and some other fibres (*pf*) crossing them, and perhaps representing fibres of Sharpey. The calcareous salts having been removed by an acid, the granular nature of the ossific deposit between the rows of cartilage-cells is not seen in this specimen; it would have extended as far as a line joining the marks × ×. Observe the general tendency of the osseous trabeculæ and the vascular channels between them to radiate from the original centre of ossification. This is found to prevail more or less in all bones when they are first formed, although the direction of the trabeculæ may afterwards become modified in relation with varying physiological conditions, and especially as the result of pressure in different directions.

be effected, as is the case with absorption of bony matter wherever it occurs, by large multi-nucleated cells (fig. 153, *f*, *f*′; fig. 156) which are termed *osteoclasts*. These are multi-nucleated giant cells like those of the marrow; they are always found on surfaces where absorption of bone is taking place, whereas on surfaces where bony deposit is proceeding osteoblasts occur.

The bone which is first formed is more reticular and less regularly lamellar than that of the adult, and contains no Haversian systems. The regular lamellæ are not deposited until some little time after birth, and their deposition is generally preceded by a considerable amount of absorption. It is about this time also that the medullary canal of the long bones is formed by the absorption of the bony tissue which occupies the centre of the shaft.

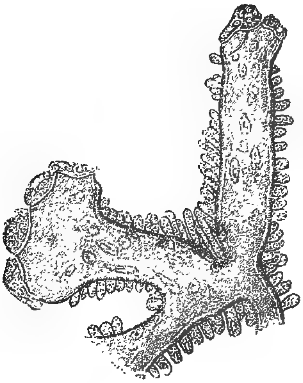

FIG. 156.—BONY TRABECULÆ FROM THE DEVELOPING LOWER JAW OF A CALF, SHOWING OSTEOCLASTS AT THE EXTREMITIES WHERE ABSORPTION IS PROCEEDING, AND OSTEOBLASTS COVERING THE SIDES WHERE DEPOSITION OF BONE IS GOING ON. (Kölliker.)

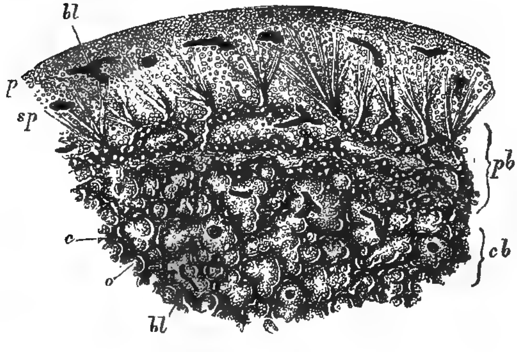

FIG. 157.—TRANSVERSE SECTION OF A DEVELOPING BONE, SHOWING THE PERIOSTEAL LAYER BECOMING FORMED FROM OSTEOGENIC FIBRES. Low power.

cb, cartilage bone; *pb*, periosteal bone; *sp*, bone spicules prolonged by osteogenic fibres; *p*, periosteum; *bl*, blood-vessels; *c*, remains of the calcified cartilage; *o*, osteoblasts forming bone upon this.

After a time the cartilage in one or both ends of the long bones begins to ossify independently, and the *epiphyses* are formed (fig. 160). These are not joined to the shaft until the growth of the bone is completed. Growth takes place in *length* by an expansion of the cartilage which intervenes between the shaft and the epiphyses (*intermediate cartilage*), and by the gradual extension of the ossification into it; *in width* entirely by the deposition of fresh bony layers under the periosteum. In the terminal phalanges of the digits the ossification starts, not from the middle of the cartilage, but from its distal extremity.

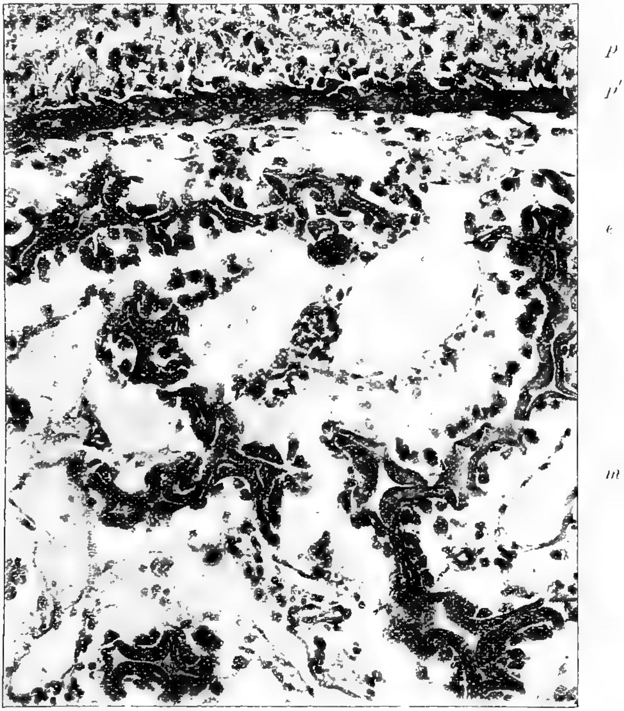

FIG. 158.—PART OF A TRANSVERSE SECTION OF A DEVELOPING LONG BONE FROM A HUMAN FŒTUS. Photograph. Magnified 200 diameters.

p, fœtal periosteum; *p'*, bone laid down in periosteum; *e*, endochondral bone composed of calcified cartilage in the centre of the septa and layers of true bone covering this; *m*, medullary spaces filled with jelly-like embryonic connective tissue and large sinus-like blood-capillaries. Notice the osteoblasts on the surfaces of the newly formed bone—both periosteal and endochondral. Two or three osteoclasts can also be seen.

For the regeneration of portions of bone which have been removed by disease or operation it is important that the periosteum be left, because a considerable amount of the blood supply comes through the vessels of the periosteum, and there are also osteoblasts on its under surface. But fragments of bone may under some circumstances undergo regeneration even after removal of the periosteum, by the agency of the osteoblasts and vessels in the marrow.

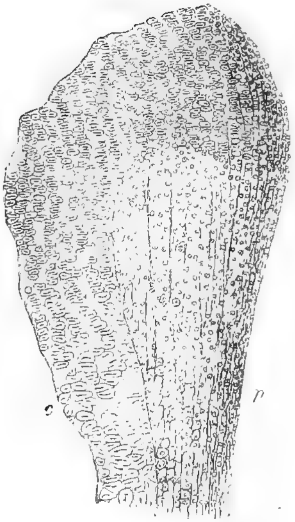

FIG. 159.—SECTION OF THE OSSIFICATION GROOVE IN THE HEAD OF A LONG BONE.

c, cartilage; *p*, periosteal tissue with osteogenic fibres and osteoblasts. This tissue occupies the "groove."

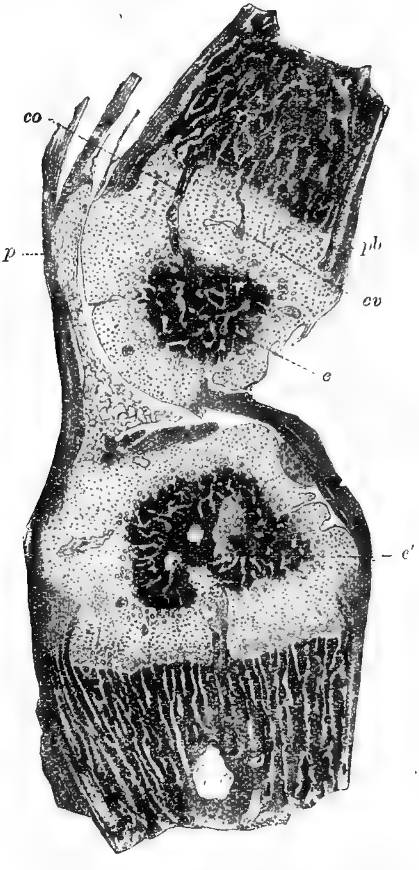

FIG. 160.—SECTION THROUGH KNEE-JOINT OF EIGHT-DAY RABBIT DURING THE FORMATION OF EPIPHYSES. (A. Bidder.)

co, canal carrying osteoblastic tissue from the diaphysis of the femur to its epiphysis; *cv*, vascular canal in cartilage; *pb*, periosteal bone; *e*, epiphysis in end of femur; *e′*, epiphysis in head of tibia; this contains an island of unossified cartilage; *p*, patella, still cartilaginous.

Intramembranous ossification.—In this variety of ossification (figs. 161, 162) the bone is not preceded by cartilage at all, and therefore no endochondral bone is formed, but the calcification occurs in an embryonic connective tissue which contains numerous osteoblasts and blood-vessels. The fibres of this tissue (osteogenic fibres) are collected into small bundles,

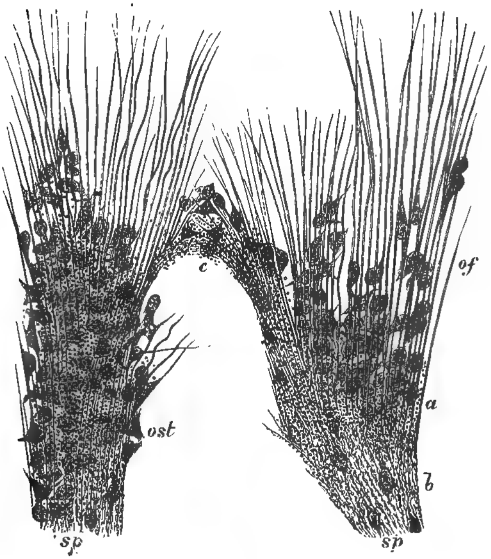

Fig. 161.—Part of the growing edge of the developing parietal bone of a fœtal cat, 1½ inch long.

sp, bone spicules, with some of the osteoblasts embedded in them, producing the lacunæ; *of*, osteogenic fibres prolonging the spicules, with osteoblasts (*ost*) between them and applied to them *a*, granular calcific deposit occurring in the ground-substance between the fibres; *c*, union of two adjacent spicules.

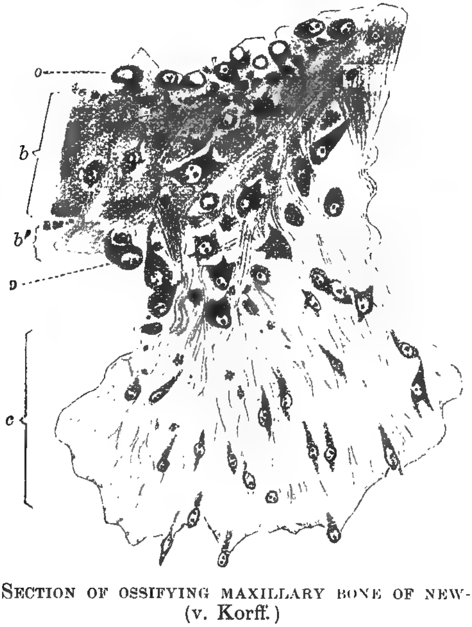

Fig. 162.—Section of ossifying maxillary bone of new-born rat. (v. Korff.)

o, *o*, osteoblasts; *b*, bony substance with osteoblasts and fibres; *b′*, growing border of bone; *c*, embryonic connective tissue, showing its fibres continuous with the osteogenic fibres of the growing border.

and become enclosed in a calcareous matrix, produced by the deposition of lime salts in the ground-substance of the connective tissue; and as the fibres grow, the calcification extends further and further, so that bony spicules are formed, which, as they become thickened, run together to form reticular layers, leaving spaces filled with jelly-like connective tissue containing osteoblasts surrounding the blood-vessels. The osteogenic fibres are covered with osteoblasts, and as the bone forms, some of these become left as bone-corpuscles within lacunæ. Thus in every particular the development of these bones resembles that of the subperiosteal layer of endochondral bone; which is, therefore, also to be considered as an instance of intramembranous ossification, although taking place on the surface of cartilage. Moreover, it is the same subperiosteal tissue which, in endochondral ossification, invades the calcified cartilage and after causing the absorption of medullary spaces within this, deposits the true or secondary bone upon those parts of the calcified cartilage-matrix which have escaped absorption; this must also, therefore, be reckoned as developed according to the same type. In fact, even in intracartilaginous ossification, very little of the calcified cartilage-matrix eventually remains; this being almost wholly absorbed and either replaced by true fibrous bone which has been formed by osteoblasts, or swept away to form the marrow cavity and other spaces in the bone.

With reference to the origin of the osteoblasts, it is believed by some authors that they are derived from the blood, being in fact leucocytes which have wandered out of the vessels and have taken on a special osteogenic function. A more reasonable view regards them as connective-tissue cells modified for the specific purpose of bone formation. They have also been thought, with less probability, to be formed by alteration of the cartilage-cells.

LESSON XIV.

STRUCTURE OF MUSCLE.

1. Take a shred of muscle from a recently killed mammal, and on a dry slide carefully separate long pieces of muscle (single fibres if possible) and stretch them out, keeping them moist during the process by breathing on the slide. Previously a drop of serum or Ringer's solution must be ready on the cover-glass to be employed to mount the preparation. Study first with a low, then with a high power. Sketch all the appearances seen in a small piece of a fibre, focussing carefully the most superficial layers. Notice the oval nuclei immediately under the sarcolemma. Then allow a little dilute acetic acid to run under the cover-glass and watch its effect.

2. Prepare some fibres of frog's muscle in the same way, mounting in frog-Ringer. Notice the muscular substance shrinking away here and there from the sarcolemma, which then becomes distinctly visible. Sketch a piece of sarcolemma bridging across an interval thus produced.

3. Study transverse sections of muscle which has been hardened in alcohol or formol and stained on a slide. Mount in dammar. Examine the section of a fibre first with a low and then with a high power. Sketch the appearances which are seen.

In each of the above preparations measure the diameter of some of the fibres.

Sections of muscle-spindles may be searched for in the transverse sections of muscle.

4. Place in 1 per cent. osmic acid a small shred of muscular tissue (mammal or crab) which has been stretched upon a cork. After 24 hours, when it will be deeply stained, wash it in water and with needles break the fibres up in glycerine as finely as possible. Cover and examine with a high power.

5. Cut off the head of a garden beetle or wasp or water beetle, and bisect the trunk with scissors so as to expose the interior. Notice two kinds of muscular tissue, the one belonging to the legs greyish in colour, the other attached to the wings yellowish. Preparations of both kinds of muscle are to be made in the same way as living mammalian muscle (§ 1), but it is better to mount them in a drop of white of egg than in serum. In both preparations the dark-looking air-tubes or tracheæ form prominent objects ramifying amongst the fibres. Observe the structure of the two kinds of muscle so far as it can be made out in the fresh preparation. If the preparation is made quickly, waves of contraction will probably be observed passing along the fibres.

6. Make another preparation of the leg-muscles, mounting the muscle in vinegar. Alcohol-hardened muscle of insect or crab may also be used for this purpose. Notice that the muscular substance swells up somewhat and becomes clearer, whilst the sarcoplasm-network, with its lines and dots, comes more distinctly into view. In a well-teased preparation made in acid, the fibres are frequently found breaking across into disks. Make careful drawings from this preparation.

7. Rollett's method. Cut off the head of an insect (wasp, small beetle), bisect the trunk and place in 90 per cent. alcohol for from 24 to 48 hours or more. Then take a small piece of each kind of muscle, and place in strong glycerine for some hours. Wash thoroughly with water and transfer to 1 per cent. chloride of gold solution: leave the pieces of muscle in this from 15 to 30 minutes according to

size. From the gold solution they are transferred to formic acid (1 part of the strong acid to 3 of water), and kept in the dark for 24 hours, but they may be kept longer without disadvantage. The muscle is then teased in glycerine. Some of the fibres will be found after this process to have their sarcoplasm darkly stained, and to show the appearance of a network both in longitudinal and transverse view: others, on the other hand, have the sarcous elements of the fibrils or sarcostyles stained, whilst the sarcoplasm has remained colourless.

8. The structure of the fibrils can also be made out in sections of the hardened wing muscles stained by the iron-hæmatoxylin method (see Appendix). This is more certain than that of Rollett and is therefore better for class purposes.

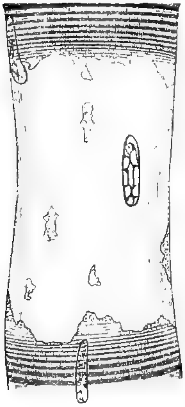

Fig. 163.

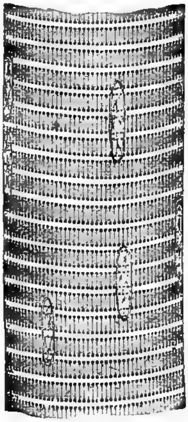

Fig. 164.

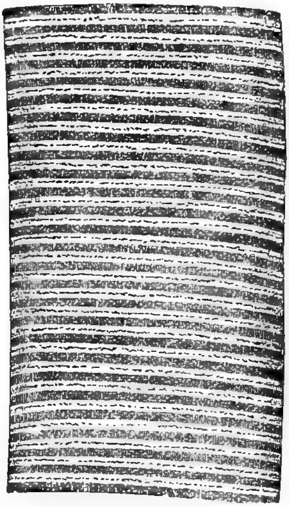

Fig. 165.

Fig. 163.—Sarcolemma of mammalian muscle highly magnified.

The fibre is represented at a place where the muscular substance has become ruptured and has shrunk away, leaving the sarcolemma (with a nucleus adhering to it) clear. The fibre has been treated with serum acidulated with acetic acid.

Fig. 164.—Muscular fibre of a mammal examined fresh in serum, highly magnified, the surface of the fibre being accurately focussed.

The nuclei are seen on the flat at the surface of the fibre, and in profile towards the edge.

Fig. 165. Portion of a medium-sized human muscular fibre, showing the intermediate line (Dobie's line) mentioned in the text. (Sharpey.)

STRIATED OR VOLUNTARY MUSCLE.

Voluntary muscle is composed of long cylindrical fibres, measuring on an average about 0·05 mm. in diameter ($\frac{1}{500}$ inch) in mammalian muscles, and often having a length of an inch or more. Each fibre has an extensible sheath, the *sarcolemma*, which encloses the contractile substance. The sarcolemma is seldom visible, unless the contained substance becomes broken (fig. 163). A fibrillar structure has been described in the sarcolemma, but under ordinary circumstances it looks completely homogeneous.

The contractile substance is characterised by the alternate dark and light stripes, which run across the length of the fibre; hence the name *cross-striated* or *striped muscle.* On focussing, it can be seen that the stripes pass through the whole thickness of the fibre; they may therefore be looked upon as representing alternate disks of dark and light substance. If the fibre be very carefully focussed, rows of apparent granules are seen lying in or at the boundaries of the light streaks, and very fine longitudinal lines may, with a good microscope, be detected uniting the apparent granules. These fine lines, with their enlargements, the granules, are more conspicuous in the muscles of arthropods (fig. 169). They indicate the divisions between the longitudinal elements (*fibrils* or *sarcostyles*) which compose the fibre, and in preparations treated with dilute acid the lines appear to form part of a fine network, which pervades the muscle substance, and serves to unite the granules both transversely and longitudinally (fig. 170). This network, which is sometimes very distinct in preparations of muscle treated with chloride of gold, is, however, a network in appearance only: in reality it is the optical expression of the interstitial substance which lies between the fibrils. This substance is termed *sarcoplasm.*

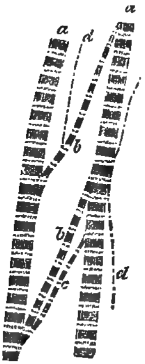

FIG. 166.

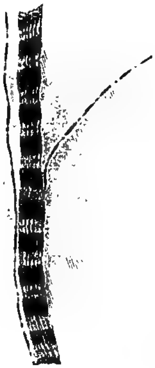

FIG. 167.

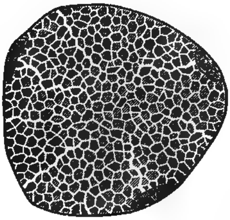

FIG. 168.

FIG. 166.—SMALL PORTION OF A HUMAN MUSCULAR FIBRE TEASED INTO SMALL LONGITUDINAL FRAGMENTS. (Sharpey.) Magnified about 800 diameters. *a*, *b*, *c*, larger and smaller groups of fibrils; *d*, ultimate fibrils.

FIG. 167.—SMALL PORTION OF A MUSCLE-FIBRE OF CRAB SPLITTING UP INTO FIBRILS. From a photograph. Magnified 600 diameters.

FIG. 168.—SECTION OF A MUSCULAR FIBRE, SHOWING AREAS OF COHNHEIM. Three nuclei are seen lying close to the sarcolemma.

On examining the transverse section of a fibre with a high power, it is seen to be subdivided everywhere into small angular fields, *Cohnheim's areas* (fig. 168), which are themselves again divided up into minute dot-like areas. The smallest divisions represent sections of the fibrils of which the fibres are composed, and into which they may be split after death (figs. 166, 167), especially after being hardened in certain reagents, *e.g.* chromic acid or osmic acid. The larger areas represent groups of fibrils. These areas of Cohnheim are usually polyhedral, but they may be elongated, and disposed either radially, or concentrically with the circumference of the section. The interstitial substance or sarcoplasm lies between the fibrils and can be made visible by treatment with dilute acid or by staining with chloride of gold (figs. 170, 171, 172). It is sometimes in relatively large amount, but in most muscular fibres is reduced to a very fine interstitium.

An ill-defined clear line is sometimes seen running transversely across the fibre in the middle of each dark band. This is termed *Hensen's line.*

If instead of focussing the surface of the fibre it be observed in its depth, an appearance different from that shown in fig. 164 is frequently visible, namely, a fine dotted line (*Dobie's line*), bisecting each clear stripe (fig. 165); this appearance is often considered to represent a membrane (*Krause's membrane*), which subdivides the fibrils at regular intervals (see p. 133). But the membranes of the individual fibrils or sarcostyles are rarely, if ever, visible in an intact mammalian fibre, and it is certain that the appearance of such a line in the middle of the clear stripe of an intact fibre is in most cases due to interference, caused by the light being transmitted between disks of different refrangibility.

Haycraft has suggested that the cross-striation of voluntary muscle is due to refractive effects produced by a varicosity of the component fibrils, basing his view upon the fact that in impressions of the fibres made on soft collodion all the cross-striations which are observed in the fibre itself are reproduced. There is no doubt that a well-marked cross-striated appearance can be produced in homogeneous fibrils by regularly-occurring varicosities, and some of the appearances observed in muscle may, as Haycraft contends, be referred to this cause. But even when a fibre or fibril is stretched so that it exhibits no varicosities, the cross-striations are still perfectly distinct. Moreover, in view of the entirely different manner in which the substance of the dark and clear stripes behave to many staining reagents, and especially to chloride of gold when applied as directed in § 7, the fact being that very definite structural appearances can under these circumstances be made out, the homogeneity of the muscle-fibril cannot be admitted. This inference is strongly confirmed by the microchemical work of A. B. Macallum, who has shown that the potassium salts of the wing muscle-fibrils are accumulated in a portion only (the sarcous elements) of the fibril (fig. 177).

Nuclei.—Besides the sarcolemma and striated substance, a muscular fibre also exhibits a number of oval nuclei which have the usual structure of cell-nuclei: their chromatin often has a spiral arrangement. Sometimes there is a little granular substance (protoplasm) at each pole of the nucleus; each nucleus with the adjacent protoplasm has then been spoken of as a *muscle-corpuscle.* But the protoplasm which is adjacent to the nuclei is in all probability continuous with the sarcoplasm between the fibrils; both being the remains of the original undifferentiated protoplasm of the cells from which the muscular fibres are developed. In the mammalian muscle the nuclei usually lie immediately under the sarcolemma (figs. 163, 164, 168), in frog's muscle they are scattered throughout the thickness of the fibre, in the leg-muscles of insects they lie in the middle of the fibre (fig. 171). Some animals, *e.g.* the rabbit, have, besides muscles of the ordinary type of structure, which in this animal are pale in colour, others of a deep red colour. These *red muscles* were found by Ranvier to exhibit certain differences both in

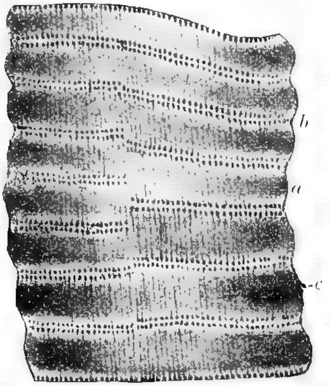

FIG. 169.—LIVING MUSCLE OF WATER-BEETLE (DYTISCUS MARGINALIS). Highly magnified.

a, dim stripe; *b*, bright stripe; *c*, fine lines, with dot-like enlargements upon them which represent the interfibrillar sarcoplasm.

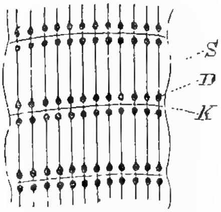

FIG. 170.—PORTION OF LEG-MUSCLE OF INSECT TREATED WITH DILUTE ACID.

S, sarcolemma; ***D***, dot-like enlargement of sarcoplasm; *K*, Krause's membrane. The sarcous elements are dissolved or at least rendered invisible by the acid.

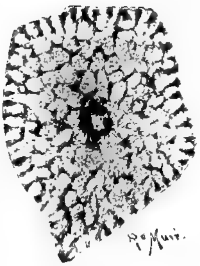

FIG. 171.

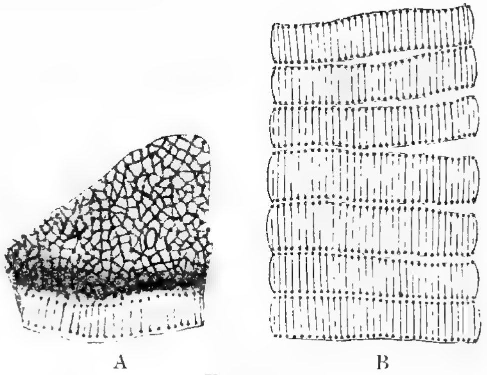

FIG. 172.

FIG. 171.—TRANSVERSE SECTION OF LEG-MUSCLE FIBRE OF AN INSECT, STAINED WITH GOLD CHLORIDE.

The sarcoplasm is here stained, and appears in the form of a network, in the meshes of which lie the sections of the fibrils. Notice the mottled appearance of the sections of the sarcostyles or fibrils, indicating a porous structure, as in the wing fibrils (see fig. 175). The central protoplasm (with a nucleus) is also evident. (From a photograph.)

FIG. 172.—LEG-MUSCLE FIBRE OF INSECT TREATED WITH DILUTE ACID, SHOWING A TENDENCY TO BREAK ACROSS INTO DISKS.

The sarcoplasm is in the form of fine lines. The ordinary dark stripes of the fibre have disappeared in the acid. *A*, a disk, seen partly in section and exhibiting the reticular arrangement of the sarcoplasm; *B*, longitudinal view of fibre.

structure and function. One difference of structure is that the nuclei, which are numerous, are not, as in the ordinary types of mammalian fibre, confined to the surface, but are scattered throughout the thickness of the fibre. The fibres in question also contain more sarcoplasm than the ordinary fibres, and their blood-vessels have a peculiarity of structure which will be afterwards noticed. It has further been shown by Grützner that in all mammals amongst the ordinary fibres are some in which the nuclei are distributed through the thickness of the fibres: this is the case, as we have seen, with all the muscular fibres of the frog. In muscles which are in constant activity, such as the diaphragm, and the dorsal fin-muscles of Hippocampus, the protoplasm (sarcoplasm) of the fibre is present in relatively large proportion; this is also the case with the wing-muscles of insects (see below).

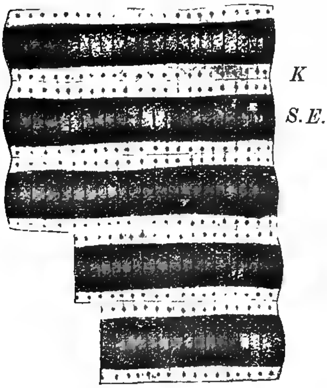

FIG. 173.—LEG-MUSCLE FIBRE OF INSECT, STAINED WITH GOLD CHLORIDE BY ROLLETT'S METHOD.

K, line formed by membranes of Krause; *S.E.*, dark stripe formed by sarcous elements. The sarcoplasm has the appearance of longitudinal lines.

The transverse section of a muscle shows the fibres to be nearly cylindrical in figure. Between the fibres there is a certain amount of areolar tissue, which serves to support the blood-vessels and also unites the fibres into fasciculi; the fasciculi are again united together by a larger amount of this intra-muscular connective tissue (*endomysium*).

Muscles of insects.—In the muscles of insects the stripes are relatively broad, and their structure can be more readily seen than in mammals. In the living fibres from the muscles which move the legs, the sarcoplasm presents a striking appearance of fine longitudinal lines traversing the muscle, and enlarging within the light stripes into rows of dots (figs. 169, 173). This is still better seen in fibres and portions of fibres which have been treated with dilute acid (figs. 170, 172). In separated disks, produced by the breaking across of muscle-fibres, the surfaces of the disks show a network with polyhedral meshes in some insects (fig. 172, A), one formed of lines radiating from the centre of the fibre in others.

The muscular fibres of the wings are considerably larger than those of the legs and contain a far greater amount of sarcoplasm, in which the fibrils are embedded. When the fibre is broken up the fibrils are easily isolated, even in the fresh tissue, and they can then be readily studied. It can be seen even in the fresh fibril, but much more distinctly after staining, that each fibril—or sarcostyle, as it is often termed—is composed of alternate dark and light portions, which by juxtaposition in adjacent fibrils produce the cross-striated appearance. Further, in the middle of each of the clear striæ is a distinct septum, known as the *membrane of Krause*, and the fibril is subdivided at regular intervals by these membranes into serial portions, which are termed *sarcomeres.* Each sarcomere is occupied by a portion of the dark stria of the whole fibre (*sarcous element*): the sarcous element is really double, and in the stretched fibril separates into two at the line of Hensen (fig. 174, B). At each end of the sarcous element is clear substance (probably fluid or semi-fluid) separating it from the membrane of Krause: this clear substance is more evident the more the fibril is extended, but diminishes, even to complete disappearance, in the retracted fibril (fig. 174, A). The cause of this change is explained when we study more minutely the structure of the sarcous element. For we find that each sarcous element is pervaded by longitudinal canals or pores, which are open in the direction of Krause's membranes, but closed at the middle of the sarcous element (figs. 174, C, D; 175, 176). In the contracted muscle, the clear part of the muscle-substance has nearly disappeared, but the sarcous element is swollen and the sarcomere is thus shortened: in the uncontracted muscle,

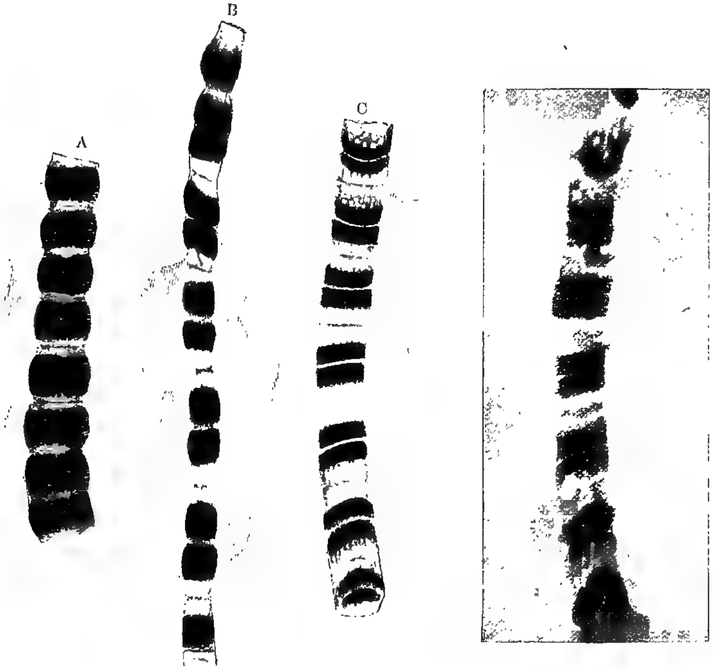

FIG. 174.—FIBRILS OF THE WING-MUSCLES OF A WASP, PREPARED BY ROLLETT'S METHOD. Highly magnified.

A, a contracted fibril. *B*, a stretched fibril, with its sarcous elements separated at the line of Henson. *C*, an uncontracted fibril, showing the porous structure of the sarcous elements. *D*, an uncontracted fibril, magnified 2000 diameters.

A, *B*, and *C* were drawn by Mr R. Muir from the preparation; *D* is an untouched photograph.

on the other hand, the clear part occupies a considerable interval between the sarcous element and the membrane of Krause, the sarcomere being lengthened and narrowed. This difference is well seen with certain methods of staining (fig. 174). The sarcous element does not lie free in the middle of the sarcomere, but is attached at either end to Krause's membrane by very fine lines, which may represent fine septa, running through the clear substance (fig. 176); on the other hand, Krause's membrane appears to be attached laterally to a fine membrane which limits the fibril externally.

The sarcous elements are set in a muscle-fibre side by side in planes forming the dark stripes (so-called *principal disks*) of the muscle-substance of ordinary muscle-fibres. In the wing-muscles of insects, the fibrils being surrounded by a considerable amount of granular sarcoplasm, the whole fibre is only very indistinctly cross-striated, although each individual fibril is markedly so. As already mentioned, the sarcous elements are remarkable for containing a large proportion of potassium salts (fig. 177).

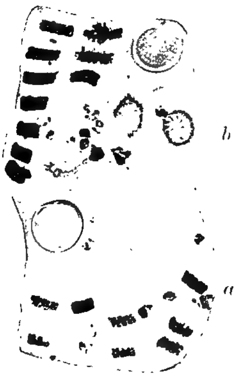

FIG. 175.—ISOLATED SARCOUS ELEMENTS OF A WING-MUSCLE, SHOWING THE TUBULAR OR POROUS STRUCTURE. Untouched photograph. Magnified 870 diameters.

At *a* some are seen in profile; at *b* on the flat. The two circular bodies are fat-drops.

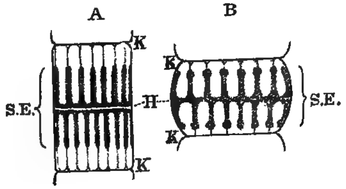

FIG. 176.—DIAGRAM OF A SARCOMERE IN A MODERATELY EXTENDED CONDITION, A, AND IN A CONTRACTED CONDITION, B.

K, *K*, membranes of Krause; *H*, line or plane of Hensen; *S.E.*, poriferous sarcous element.

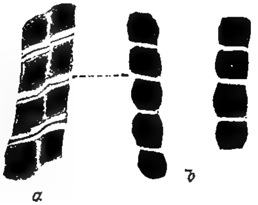

FIG. 177.—LOCALISATION OF POTASSIUM IN SARCOUS ELEMENTS OF WING-MUSCLE OF BEETLE. (A. B. Macallum.)

a, resting; *b*, contracted.

Sometimes in the ordinary (leg) muscles of arthropods what look like detached dot-like portions of the sarcous element are seen within the clear stripes, lying usually near Krause's membrane. The rows of such dots have been termed *accessory disks*. Most muscles show no accessory disks, but the sarcoplasm enlargements between the fibrils (fig. 170, D) are often mistaken for them.

Muscle in polarised light.—When muscle-fibres are examined with polarised light between crossed nicols, the sarcous elements (which form the dark stripe) are seen to be doubly refracting (anisotropous), while the clear substance (forming the light stripe) is singly refracting (isotropous). In contracted parts of the muscle the (anisotropous) sarcous elements are seen to have increased in bulk, while the isotropous substance of the clear stripe has correspondingly diminished (fig. 178, B).

Merkel described a reversal of the stripes during contraction, *i.e.* a transference of the anisotropous substance of the dark stripe from Hensen's line to Krause's membrane, the place of the dark stripes thus becoming occupied by clear material, that of the light stripes by dark. He further described this condition as being preceded by an intermediate stage in which the fibril shows homogeneity of shading. No doubt in the ordinary muscle-fibres of arthropods, when we observe the so-called "fixed" waves of contraction, there is an apparent blurring of the cross-striation of the fibre just where the muscle is passing from extension to contraction, but this appearance is explicable by the unequal pull of the contracted parts of the fibrils upon those which are not yet contracted. The contraction in each fibre starts from the nerve-ending, which is at one side of the fibre, and spreads first across the fibre and then tends to pass as a wave towards either end. But the one side always has a start in the progress of this wave, and the fibrils must thus receive an unequal pull, so that they are shifted along one another and the line of cross-striping is broken up. That no transference of anisotropous substance really occurs is at once clear from the appearance of the contracting fibre under polarised light (fig. 178, B), and the study of the isolated fibrils of wing-muscle gives no support to the theory of reversal, although it is widely held by German authors. That the apparent reversal is not real is also illustrated by fig. 179, which represents a leg-muscle fibre of an insect in process of contraction.

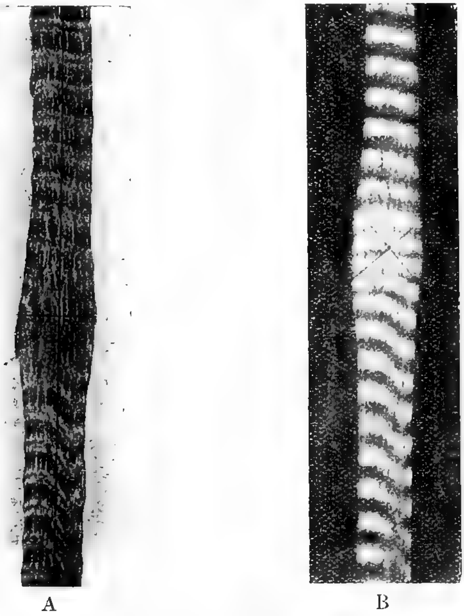

FIG. 178.—LEG-MUSCLE FIBRE OF CHRYSOMELA CŒRULEA WITH (FIXED) CONTRACTION WAVE PHOTOGRAPHED UNDER POLARISING MICROSCOPE.[1]

A, with uncrossed nicols; *B*, with crossed nicols.

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[1] I am indebted to the late Professor Engelmann for these two photographs.

The dark bands of the contraction-wave are seen to be really due to the accumulations of sarcoplasm. Owing to its having a higher index of refraction the accumulations appear as dark lines which obscure the continuity of the fibrils, and by contrast cause the whole of the sarcomeres between them to appear light.

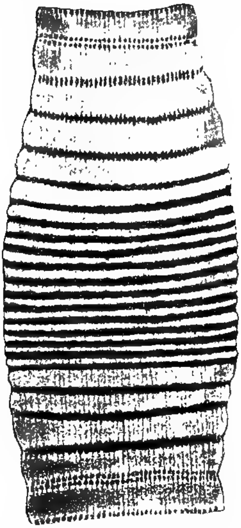

FIG. 179.—WAVE OF CONTRACTION PASSING OVER A LEG-MUSCLE FIBRE OF DYTISCUS. Highly magnified.

Mechanism of contraction.—Comparing the structure of the sarcomere with certain kinds of protoplasm we find both differentiated to form a framework (spongioplasm, substance of sarcous element) which encloses in its meshes or pores a clear, probably fluid substance (hyaloplasm, clear substance of sarcomere). In both also the clear substance or hyaloplasm, when the tissue is subjected to stimulation, passes into the pores of the porous substance or spongioplasm (contraction), whilst in the absence of such stimulation it tends to pass out from the spongioplasm (formation of pseudopodia, resting condition of muscle). The effect of stimulation appears in both structures to be the production of a change in surface tension (perhaps between the hyaloplasm and spongioplasm); this change being demonstrably accompanied in muscle by a difference in electric potential: possibly such an electric change occurs in all protoplasm. Thus both the movements of cell-protoplasm and those of muscle are in all probability brought about by like means, although at first sight the structure of muscle is very dissimilar from that of protoplasm. We have already noticed that the movements of cilia are also capable of being explained by assuming rhythmic variations of surface tension in the protoplasm of the cells to which they are attached.

Macdonald has suggested that the movement of fluid from one part of the sarcomere to the other is a result of osmosis, caused by the sudden setting free of electrolytes (potassium salts) in the substance of the sarcous element just previous to the actual contraction. MacDougall had previously opined that such osmosis might occur between the interior of the fibril and the sarcoplasm outside, and Meigs, who holds a similar view, considers that the diffusion of fluid is facilitated by a prior development of lactic acid in the sarcous elements as a result of stimulation. Many reasons may be urged against this idea: some of them are set forth in a paper in the *Quart. Journ. Exper. Physiol.*, vol. iii., 1910, p. 63: but the discussion of the matter here would occupy too much space.

LESSON XV.

STRUCTURE OF MUSCLE (*continued*).

1. To study the connexion of muscle with tendon, a frog is killed by destruction of the brain and spinal cord, and placed in about a litre of water raised to a temperature of 55° C. It is left in this for 15 minutes, the water gradually cooling. It is then easy to dissociate the muscular fibres in large numbers. To observe their attachment to the tendon-bundles a fine longitudinal shred must be snipped off with scissors at the tendinous attachment, and dissociated upon a slide in a drop of Ringer. It will usually be found that the muscular substance is retracted from the end of the sarcolemma tube, which is firmly cemented to the tendon-bundle. The structure may be brought more distinctly into view by adding to the dissociated fibres a drop of a weak solution of iodine in salt solution or in serum (iodised serum).[1]

2. The blood-vessels of muscle. These are studied in longitudinal and transverse sections or in flattened-out pieces of injected muscle. It will be noticed that the capillaries are very numerous, and form a network with oblong meshes. In the red muscles of the rabbit, small dilatations are seen on the transverse cords of the network.

3. The muscular tissue of the heart is studied in sections of that organ (see Lesson XXVII.) and also in teased preparations. To prepare the latter, place a small piece of heart-muscle in 33 per cent. alcohol for a few days; stain in picro-carmine solution for some days; tease in dilute glycerine.

4. Tear off a small shred of the circular muscular coat of a piece of dog's or cat's intestine which has been for 48 hours or more in $\frac{1}{5}$ per cent. bichromate of potassium solution or in 33 per cent. alcohol. Hold the shred with forceps in a drop of water on the slide and fray it out with a needle. In this process many cells will be set free and can be found with a low power. The preparation may then be covered and examined with a high power. Sketch one of the cells. Then allow a small drop of very dilute hæmatoxylin solution to diffuse under the cover-glass; to be followed by a small drop of dilute glycerine. Sketch a cell after staining. Measure two or three cells and their nuclei. Sections of involuntary muscle will be seen and studied along with the viscera which possess muscular coats.

CONNEXION WITH TENDON: BLOOD-VESSELS: DEVELOPMENT OF STRIPED MUSCLE.

Ending of muscle in tendon.—A small tendon-bundle passes to each muscular fibre and becomes firmly united with the sarcolemma which extends over the end of the fibre (fig. 180). Besides this attachment, a further connexion is established by the fact that the areolar tissue between the tendon-bundles is continuous with that which lies between the muscle-fibres. There is no actual continuity between contractile substance and tendon (Boeke).

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[1] This method is the one given by Ranvier (*Traité Technique*, p. 395). The muscle-endings may also sometimes be well seen at the extremities of the tendons which are removed from the mouse's tail in the manner described in Lesson X.

Blood-vessels of muscle.—The capillaries of muscular tissue are very numerous. They run, for the most part, longitudinally, with transverse branches, so as to form long oblong meshes (fig. 181). No blood-vessels ever penetrate the sarcolemma. In the red muscles of the rabbit, the transverse capillaries have small dilatations upon them (fig. 182). Associated with this and other peculiarities of structure (see p. 131), it is found that the red muscles have a much slower rate of contraction, and a much longer period of latency than the ordinary muscles.

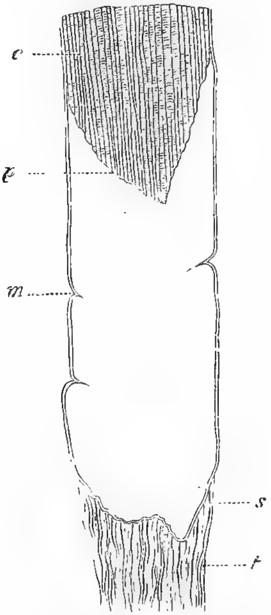


FIG. 180.—TERMINATION OF A MUSCULAR FIBRE IN TENDON. (Ranvier.)

m, sarcolemma; *s*, the same membrane passing over the end of the fibre; *p*, extremity of muscular substance, *c*, retracted from the lower end of the sarcolemma-tube; *t*, a tendon-bundle passing to be fixed to the sarcolemma.

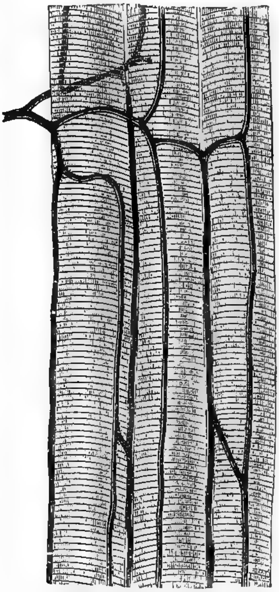


FIG. 181.—CAPILLARY VESSELS OF MUSCLE: HUMAN.

Lymph-vessels, although present in the connective-tissue sheath (perimysium) of a muscle, do not penetrate between the component fibres.

The **motor nerves** of voluntary muscles pierce the sarcolemma and terminate in ramified expansions known as *end-plates* or *motor end-organs*; the *sensory nerves* end in groups of specially modified muscle-fibres known as *muscle-spindles* (see Lesson XIX.).

Development.—Voluntary muscular fibres are developed from embryonic cells of the mesoderm (muscle-plate), which become elongated, and the nuclei of which become multiplied, so as to produce long slender, multi-nucleated fusiform or cylindrical embryonic fibres. It is not quite certain whether, as has usually been supposed, the whole fibre is thus formed of a single enlarged cell, or whether it may be produced by the joining together, end to end, of a number of cells of the muscle-plate (or even of more than one muscle-plate), so as to produce a syncytium, within which the striated fibrils make their appearance. These appear at first along one side of the embryonic fibre, the change gradually extending around the circumference and also penetrating towards the centre; but the protoplasm both at the middle of the fibre, to which the nuclei are at first confined, and at the side opposite to that at which the differentiation began, remains for some time unaltered in character (fig. 183). Eventually the change in structure extends to these parts also, and the nuclei pass gradually to occupy their ordinary position under the sarcolemma, which has by this time become formed. The sarcolemma is believed to be produced, not by the muscle-fibre itself, but by the mesenchyme or connective-tissue cells between the fibres, since it is directly continuous with the connective-tissue bundles of the tendon and of the interstitial tissue.

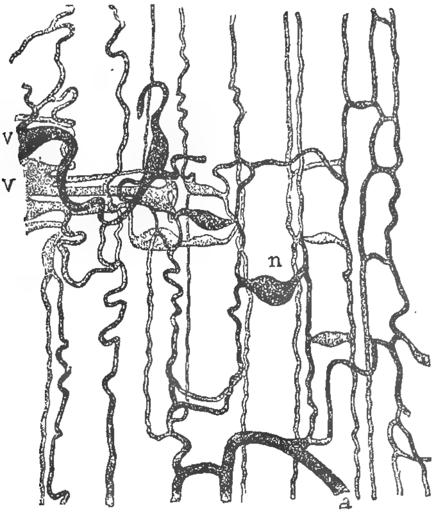


FIG. 182.—VASCULAR NETWORK OF A RED MUSCLE (SEMI-TENDINOSUS) OF THE RABBIT. (Ranvier.)

a, arteriole; *v*, *v*, venules; *n*, dilatation on transverse branch of capillaries.

CARDIAC MUSCLE.

The muscular substance of the heart is composed of transversely striated muscular fibres, which differ from those of voluntary muscle in the following particulars, viz.:—their striations are less distinct; they have no sarcolemma, although there is a thin superficial layer of non-fibrillated substance; they branch and unite by their branches and also at the side with neighbouring fibres, and their nuclei lie in the substance and often near the centre of the fibres. In man and many mammals the fibres are marked off into a series of short cylindrical cells (figs. 184, 185) joined together end to end and side to side, each corresponding to one of the nuclei. The junctions of these cells may be seen in longitudinal sections of appropriately stained fixed tissue; they also come distinctly into view in sections of fresh tissue stained with nitrate of silver. They appear to be bridged across by fine fibrils, continued into the cells above and below the lines of junction (figs. 186, 187). These lines have usually been regarded as intercellular spaces separating the constituent cells of the tissue from one another (Schweigger-Seidel). Some authorities, however, are inclined to regard the cardiac muscular

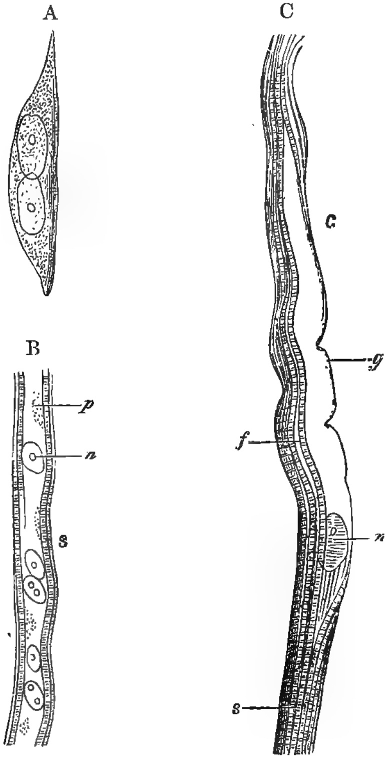


FIG. 183.—DEVELOPING MUSCULAR FIBRES.

A, elongated cell with two nuclei. A striation is beginning in the protoplasm along one side of the cell; from fœtal sheep. (Wilson Fox.)

B, from human fœtus of two months. (Ranvier.) *p*, central protoplasm with several nuclei, *n*, scattered in it; *s*, commencing sarcolemma, with striated muscular substance developing immediately beneath it.

C, from human fœtus of three months. (Ranvier.) The contractile substance, *s*, *f*, now almost encloses the unaltered protoplasm, *g*; only one nucleus, *n*, is represented.

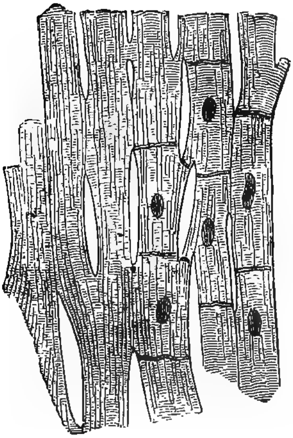


Fig. 184.—Muscular fibres from the heart, magnified, showing their cross-striæ, divisions, and junctions. (Schweigger-Seidel.)

The nuclei and cross-lines are only represented on the right-hand side of the figure.

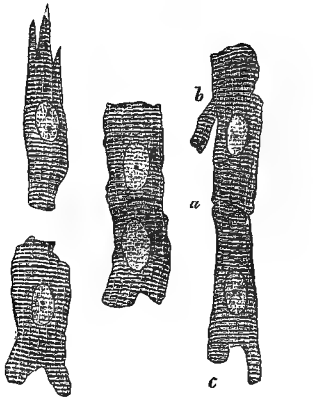


Fig. 185.—Six muscular fibre-cells from the heart. Magnified 425 diameters.

a, line of junction between two cells; *b*, *c*, branching of cells. (From a drawing by J. E. Neale.)

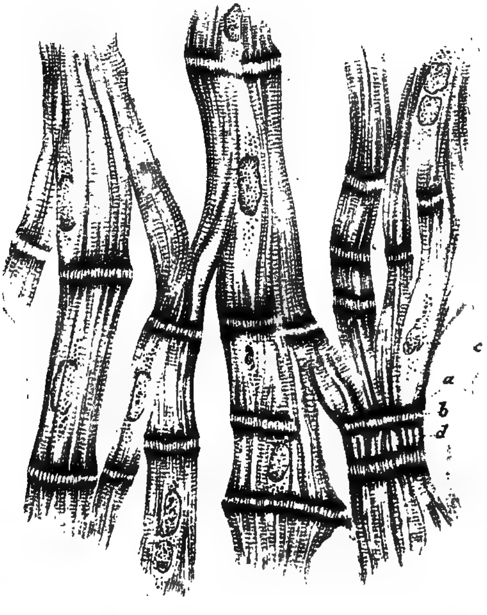


Fig. 186.—Cardiac muscle-fibres, showing their branching and junctions. (Przewosky.)

The cross-lines (junctions) are very well marked. In some of the fibres, as at *a*, two junctional lines are close together with a non-nucleated portion, *d*, between them; *b*, fibrils passing across junction; *c*, a nucleus.

tissue as forming a syncytium, the cells being all continuous both laterally and longitudinally, and the apparent intercellular lines being special differentiations. H. E. Jordan and other authorities regard these lines as due to fixed localised contractions; Martin Heidenhain considers that they represent portions of the fibres at which growth in length occurs (analogous to the suture-lines between the flat bones of the cranium). As against these views of the structure of the heart-muscle, and in favour of that of Schweigger-Seidel, must be set the silver-staining of the supposed cell-junctions, and the fact that it is easily possible in some animals to separate the fibres after maceration into short uninucleated fragments (as in fig. 185).

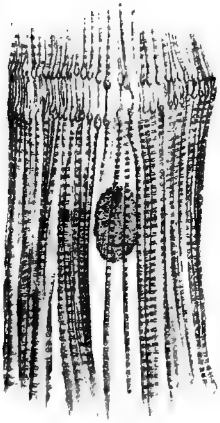


FIG. 187. PORTION OF CARDIAC MUSCLE EXHIBITING CONTINUITY OF FIBRILS ACROSS JUNCTIONAL LINE. (Przewosky.) Highly magnified.

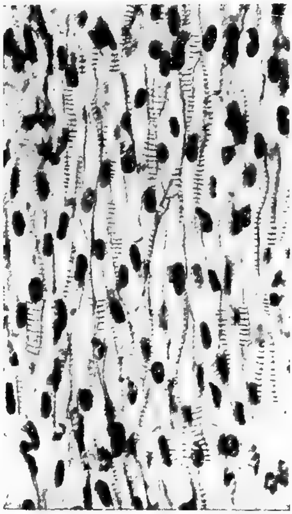
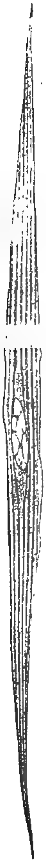


FIG. 188.—SECTION FROM HEART OF FIVE MONTHS' EMBRYO: HUMAN. (G. Mann.)

Schweigger-Seidel's view has been recently upheld by the observations of v. Palczewska and Werner (working with Zimmermann), who have studied the subject in the heart of man and of various mammals. These observers point out, as had been previously done in this work, that the short non-nucleated lengths of fibres (fig. 186), which Heidenhain regards as fatal to the cell-theory of cardiac muscle, may be parts of cells lying in other planes of the myocardium, which are inserted between those belonging to the plane included in the longitudinal section. On the other hand, the continuity of the muscular fibrils within the masses of Purkinje's fibres under the endocardium in the sheep, the fibrils belonging to one cell being freely continued into those of the neighbouring cells (see fig. 399, p. 288), is in favour of the syncytial theory. Further, in many vertebrates, including some mammals, no cell-territories can be made out in the myocardium.

The explanation of these differences appears to lie in the fact that in all animals the heart-muscle at a certain period of development (fig. 188) forms a syncytium of coalesced cells within which the contractile fibres are developed, and only in mammals is a differentiation of the syncytium into cells produced later; even here the lines of junction are bridged across by the muscle-fibrils.



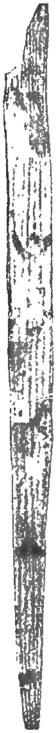


Fig. 190.

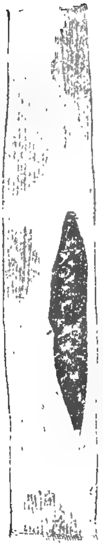


Fig. 191.

Fig. 189.—Muscular fibre-cell from the muscular coat of the small intestine. Highly magnified: A complete cell, showing the nucleus with intranuclear network, and the longitudinal fibrillation of the cell-substance.

Fig. 190.—Portion of a plain muscle-cell, showing fibrils within its cytoplasm. Photograph. Magnified 450 diameters.

Fig. 191.—Plain muscle-fibre, showing nucleus, centriole, and cytoplasm with fibrils. (Lenhossék.)

Fig. 189.

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* It is usually stated that there is no sarcolemma in cardiac muscle-fibres, but v. Palczewska and Werner describe and figure a membrane covering the cardiac cells which they regard as equivalent to the sarcolemma of voluntary muscle.

NON-STRIPED, SMOOTH, OR PLAIN MUSCLE.

Involuntary or **plain muscular tissue** is composed of long, somewhat flattened, fusiform cells (figs. 189, 190), which vary much in length. In cross section they are usually angular, an appearance due to mutual compression (fig. 192). Each cell has an oval or rod-shaped nucleus, which shows the usual intranuclear network and commonly one or two nucleoli. There is a centriole—sometimes double—close to the nucleus (fig. 191). The cell-substance is finely fibrillated, but does not exhibit cross-striæ like voluntary muscle. There appears, as in cardiac muscle, to be a delicate external layer, probably a stratum of undifferentiated protoplasm, not a true sarcolemma. Next to this, in some smooth muscle, is a layer containing coarser fibrils (boundary fibrils of M. Heidenhain) (fig. 190). Frequently there are seen on involuntary fibres a series of somewhat irregularly placed transverse markings which appear as knot-like condensations of the cell-substance (fig. 190) staining somewhat differently from the rest of the cell. The nature of these is not well understood, but they are perhaps fixed contraction waves (C. M'Gill); the fibrils are enlarged as they run through the knots. The intercellular substance is bridged across by filaments passing from cell to cell (fig. 193). Some authorities, however, deny that the

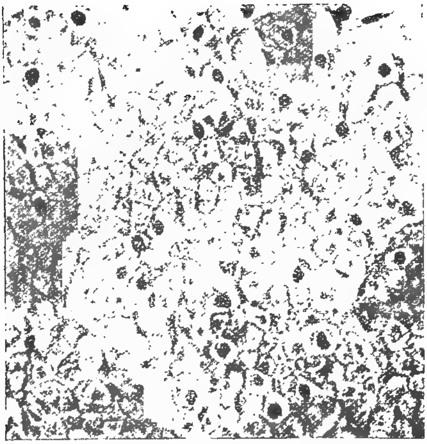

FIG. 192.—TRANSVERSE SECTION OF PLAIN MUSCLE-FIBRES OF INTESTINE. Photograph. Magnified 400 diameters.

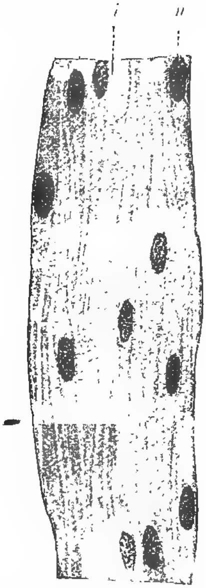

FIG. 193.—MUSCLE-CELLS OF INTESTINE. (Szymonowicz.) Magnified 530 diameters.

The fibres are represented in longitudinal section; and interstices between them are seen to be bridged across by fine fibrils. *i*, interstice; *n*, nucleus.

involuntary cells are thus connected, and hold that the appearance of bridging fibres is due to connective-tissue fibres between the cells. It is, however, difficult to understand how the contractions are propagated from cell to cell if there is no continuity between the cells.

Plain muscular tissue is found chiefly in the walls of hollow viscera; thus it forms the muscular coat of the stomach and intestines, and occurs abundantly in the muscular coat of the gullet, although it is here intermixed with cross-striated muscle; it is found also in the mucous membrane of the whole alimentary canal from the œsophagus downwards; in the trachea and its ramifications; in the urinary bladder and ureters; in the uterus and Fallopian tubes; in the prostate; the spleen and lymphatic glands; the muscle of Müller in the orbit, and in the ciliary muscle and iris. The walls of gland-ducts also contain it; and the middle coat of the arteries, veins, and lymphatics is largely composed of this tissue. It occurs in the skin, both in the secreting parts of the sweat glands, and in small bundles attached to the hair-follicles; in the scrotum it is found abundantly in the subcutaneous tissue (dartos), and it also occurs in the areola of the nipple.

Development.—According to the observations of C. M'Gill, the smooth muscle of the alimentary canal (pig) is developed from a syncytium of mesenchyme cells which surrounds the entoderm. Some of these cells become elongated and spindle-shaped while retaining their inter-connexion. Myofibrils are developed in their protoplasm. These are not confined to the limits of a single cell, but extend over two or even a large number of cells. The myofibrils are of two kinds, coarse and fine, varying in relative number in different parts. As stated above, an inter-connexion of the cells probably obtains even in the fully formed muscle, which thus retains something of its syncytial character.

In certain situations smooth muscle is formed from epithelium; this is the case with the muscular tissue of the sweat glands (Ranvier) and that of the iris (Nussbaum, Szili).

LESSON XVI.

THE TISSUES OF THE NERVOUS SYSTEM.

1. **Tease** a piece of fresh nerve (vagus by preference) rapidly in Ringer; or by the method of semidesiccation, keeping the preparation moist by the breath, afterwards mounting in Ringer. Touch the fibres as little and obtain them as long and straight as possible. Study the medullated fibres, carefully noticing all the structures that are visible—viz., nodes of Ranvier, nuclei of neurolemma, double contour of medullary sheath, medullary segments, etc. Besides the ordinary fibres, very fine medullated fibres, and also non-medullated, will be seen in this preparation. Measure the diameter of four fibres. Draw a short length of one or more fibres very exactly. The preparation may then be stained by dilute magenta and gentian violet solution and preserved with dilute glycerine.

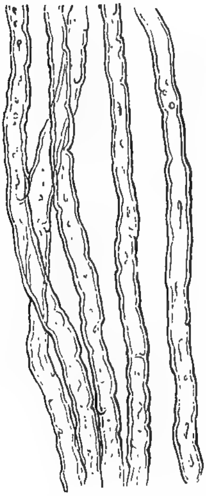

Fig. 194.—White or medullated nerve-fibres, showing a sinuous outline and double contours. (Sharpey.)

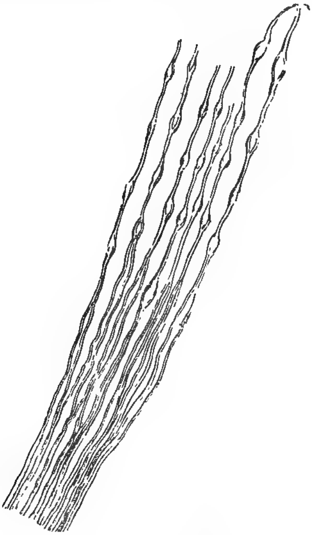

Fig. 195.—Fine medullated nerve-fibres, parts of which have acquired a varicose appearance—probably the result of manipulation.

2. Separate (in dilute glycerine coloured by magenta and gentian violet) into its fibres a small piece of nerve (or of a nerve-root: this is much more easy to separate into its fibres) that has been twenty-four hours in 1 per cent. osmic acid. The nerve should have been moderately stretched on a piece of cork by means of glass pins before being placed in osmic acid. Keep the fibres as straight as possible and only touch them near their ends with the needles. Sketch two portions of a medullated fibre under a high power, one showing a node of Ranvier and the

other a nucleus of the neurolemma. Look for pale fibres. Measure the length of a nerve segment between two nodes of Ranvier.

3. Mount in dammar sections of a nerve which has been fixed with picric acid followed by alcohol, or with osmic acid followed by alcohol. The sections from picric may be stained with picro-carmine or hæmatoxylin. The nerve should be pinned out straight upon a cork with glass pins before being placed in the fixing solution. Examine the sections first with a low and afterwards with a high power. Notice the lamellar structure of the perineurium, the varying size of the nerve-fibres, the axis-cylinder in the centre of each fibre, etc. Measure the diameter of four fibres. Sketch a small portion of the section.

4. Teased preparations and longitudinal sections from the peripheral portions of nerves cut a few days before death. The nerves may be prepared with osmic acid as in § 2. Notice the breaking up of the myelin of the medullary sheath, varying in degree according to the length of time the lesion was made previous to death. In longitudinal sections of the central cut end of the nerve, prepared by Cajal's reduced silver method,[1] new fibres may be seen budding from the extremities of the fibres of the stump.

STRUCTURE OF NERVE-FIBRES.

Nerve-fibres are of two kinds, *medullated* and *non-medullated.* The cerebro-spinal nerves and the white matter of the nerve-centres are composed of medullated fibres; the sympathetic nerves near their peripheral distribution are largely made up of non-medullated fibres. The latter are also found in considerable numbers in the vagus.

The **medullated** or **white fibres** are characterised, as their name implies, by the presence of the so-called *medullary sheath* or *white substance.* This is a layer of soft substance, of a fatty or rather lipoid nature, which encircles the

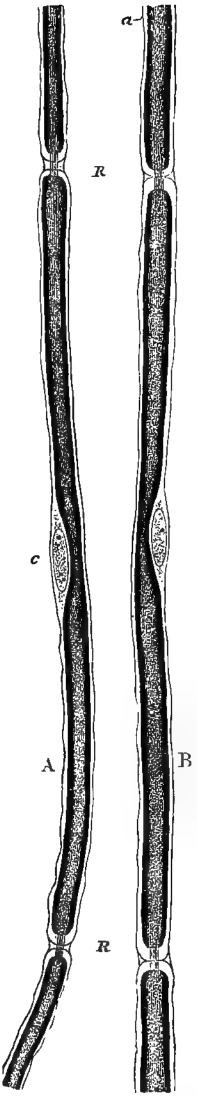

FIG. 196.—PORTIONS OF TWO NERVE-FIBRES STAINED WITH OSMIC ACID, FROM A YOUNG ANIMAL. Diagrammatic. (Drawn by J. E. Neale.)

R, R, constrictions of Ranvier, with axis-cylinder passing through. *a*, neurolemma of the nerve; *c*, opposite the middle of the segment, indicates the nucleus and protoplasm lying between the neurolemma and the medullary sheath. In *A* the nodes are wider, and the intersegmental substance more apparent than in *B*.

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[1] See Appendix.

essential part of a nerve-fibre, viz., the *axis-cylinder.* Outside the medullary sheath is a delicate but tough homogeneous membrane, the *primitive sheath* or *nucleated sheath of Schwann*, but this is not present in all medullated fibres, being absent in those which are within the nerve-centres. The primitive sheath is also known as the *neurolemma.*[1]

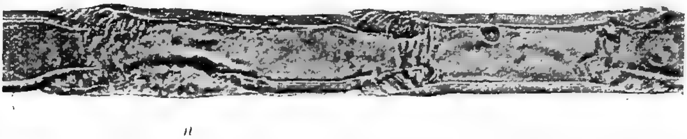

FIG. 197.—A SMALL PART OF A MEDULLATED FIBRE. Photograph. Magnified 600 diameters.

The fibre looks in optical section like a tube—hence the term tubular formerly applied to these fibres. Three partial breaches of continuity (medullary clefts) are seen in the medullary sheath, which at these places exhibits a tendency to split into laminæ. Elsewhere the medullary sheath shows coagulation-appearances. At *n* is a nucleus belonging to the neurolemma, embedded in protoplasm ; the outline of the nucleus itself is not focussed.

FIG. 198.—MEDULLATED NERVE-FIBRE, FRESH, SHOWING A NODE OF RANVIER. Photograph. Magnified 600 diameters.

The coagulation of the substance of the medullary sheath is advanced, and the axis-cylinder is slightly shrunken away from it, and is thus rendered distinctly visible.

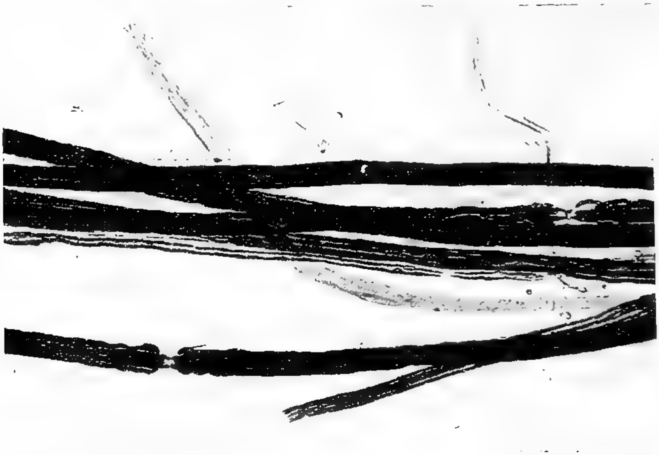

FIG. 199.—OSMIC NERVE-FIBRES FROM SCIATIC NERVE INCLUDING A NON-MEDULLATED FIBRE AND A VERY FINE MEDULLATED FIBRE. Photograph. Magnified 300 diameters.

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[1] Often erroneously termed "neurilemma," a name formerly applied to the sheath of Henle (see p. 155).

The *medullary sheath* is composed of a highly refracting lipoid material (myelin), which gives a characteristic double contour and tubular appearance to the nerve-fibre (fig. 194). It affords a continuous investment to the axis-cylinder, except that, as was shown by Ranvier, in the peripheral nerve-fibres it is interrupted at regular intervals. At these places the neurolemma appears to produce a constriction in the nerve-fibre (figs. 196, 198, 199, 200, 202), and the interruptions of the medullary sheath are accordingly known as the *constrictions* (Ranvier) or *nodes*, the latter term being applied from the resemblance which they bear to the nodes of a bamboo. It is, however, uncertain whether the constriction is entirely occupied by neurolemma or partly by a special band (*constricting band* of Ranvier); if the latter, it is composed of a material which resembles intercellular substance in its reaction to nitrate of silver (fig. 210). The length of nerve between two successive nodes is termed an *internode*; in the middle of each internode is one of the nuclei of the neurolemma. Besides these interruptions of Ranvier the medullary sheath shows a variable number of oblique clefts (figs. 197, 200, 202), subdividing it into irregular portions, which have been termed *medullary segments*; there is some reason to believe that the clefts are artificially produced. At the clefts there is an appearance of spiral fibres in the medullary sheath, especially after treatment of the nerve with certain reagents; it is, however,

FIG. 200.—NERVE-FIBRE PREPARED WITH OSMIC ACID. Photograph. Magnified about 500 diameters.

A constriction of Ranvier is seen. The intervals between the medullary segments appear as clear oblique lines.

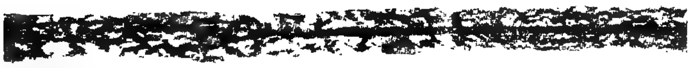

FIG. 201.—RETICULUM OF NEUROKERATIN IN MEDULLARY SHEATH OF NERVE-FIBRE. Photograph. Magnified 600 diameters.

probable that this appearance also does not represent a pre-existing structure. A reticular appearance has been noticed in the medullary sheath (*neurokeratin network* of Kühne, fig. 201), and can be readily seen in nerve-fibres fixed in alcohol and treated with ether, but it varies greatly in aspect, and is perhaps produced by the action of the reagents employed to show it. By other modes of fixation (*e.g.*, picric acid) the medullary sheath seems to have a rod-like structure (fig. 203); this again may be due to the manner in which certain of its constituents are coagulated by the reagent. Osmic acid stains the medullary sheath black (figs. 199, 200, 202, 204).

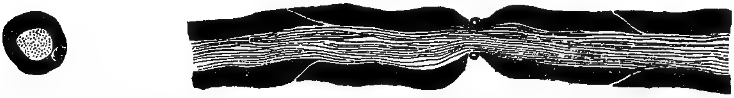

FIG. 202.—LONGITUDINAL AND TRANSVERSE SECTION OF MEDULLATED NERVE-FIBRE OF FROG (OSMIC ACID AND ACID FUCHSIN). (After Biedermann.)
The longitudinal section shows one node of Ranvier and two medullary clefts. The fibrillar structure of the axis-cylinder is shown in both longitudinal and transverse section.

The *axis-cylinder*, which runs along the middle of the nerve-fibre, is a soft transparent thread which is continuous from end to end of the fibre. On account of the peculiar refractive nature of the medullary sheath it is difficult to see the axis-cylinder in the fresh nerve except at the nodes, where it may be observed stretching across the interruptions in the medullary sheath: it may also sometimes be seen projecting from a broken end of a nerve-fibre. It is longitudinally striated, being made up of extremely fine fibrils (*neuro-fibrils*, fig. 202). They are seen isolated at the terminations of nerves as in the cornea and are also visible in the section of a nerve-fibre as fine dots (fig. 202), which sometimes appear to have a clear centre (fig. 203), as if the fibrils were tubular. Staining with nitrate of silver produces a curious transversely striated appearance in the axis-cylinder (Frommann) (fig. 210, C); this is due to successive precipitations of chlorides, and does not indicate a pre-existing structure (A. B. Macallum).

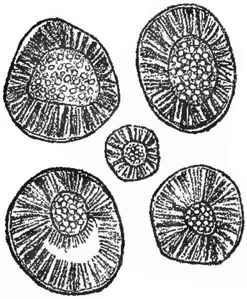

FIG. 203. — SECTION ACROSS FIVE NERVE - FIBRES. Magnified 1000 diameters.
The nerve was hardened in picric acid and stained with picro-carmine. The radial striation of the medullary sheath is very apparent. In one fibre the rays are broken by shrinkage of the axis-cylinder. The fibrils of the axis-cylinder appear tubular. (From a photograph.)

Medullated nerve-fibres vary greatly in size (fig. 204), but may be classified as *large*, *intermediate*, and *very small*. The largest are those which are passing to the skin and to the voluntary muscles; the smallest are those which are distributed to the viscera and blood-vessels by way of the

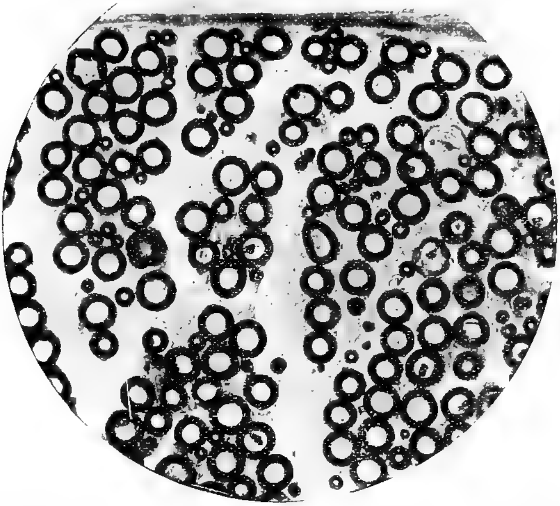

FIG. 204.—SECTION OF THE SCIATIC NERVE OF A CAT, SHOWING THE VARIATIONS IN SIZE OF ITS CONSTITUENT FIBRES. Photograph. Magnified 300 diameters. The nerve was fixed with osmic acid.

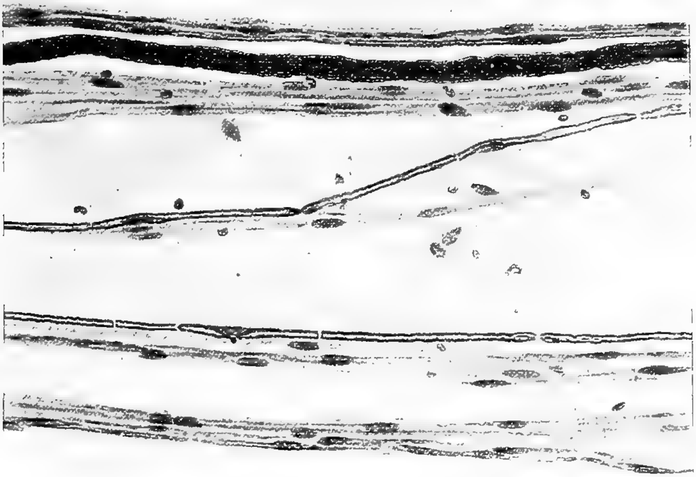

FIG. 205.—NON-MEDULLATED FIBRES FROM A TEASED PREPARATION OF VAGUS OF CAT FIXED WITH OSMIC ACID. Photograph. Magnified 300 diameters.

About a dozen non-medullated fibres are included in the photograph. Besides these one ordinary medullated fibre and three very fine medullated fibres are seen.

autonomic nerves.[1] As shown by Gaskell, the anterior roots of the last one or two cervical nerves, of all the thoracic, of the first and second lumbar, and of the second and third sacral nerves contain, besides the ordinary large medullated fibres, a bundle of very small medullated fibres, which are destined for the viscera and blood-vessels, and which pass to them by way of the sympathetic system. The roots of some of the cranial nerves (the spinal accessory, vagus, glosso-pharyngeal, and facial) contain similar fine medullated fibres, which pass amongst the larger fibres to their distribution at the periphery.

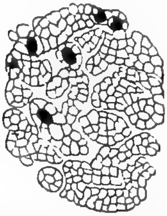

FIG. 206.—SECTION ACROSS NON-MEDULLATED FIBRES (FROM THE SPLENIC NERVE OF THE OX.) (Tuckett.)

Non-medullated fibres.—Intermingled with the medullated fibres there may always, even in the cerebro-spinal nerves, be found a certain number of pale fibres devoid of the distinct double contour which is characteristic of the presence of a medullary sheath (see fig. 205). These are the *grey* or *non-medullated fibres*, also called, after their discoverer, *fibres of Remak*. They frequently branch, which the medullated fibres rarely do except near their termination, and

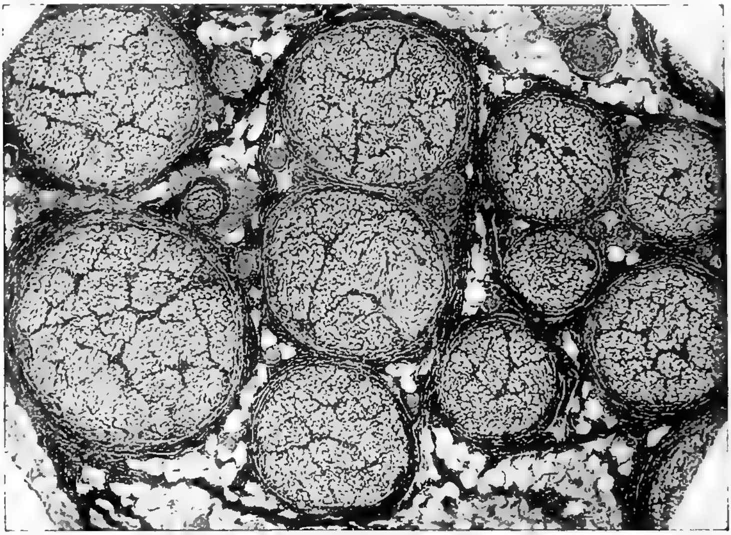

FIG. 207.—SECTION OF PART OF SCIATIC NERVE OF MAN. Photographed from a preparation by H. Pringle. Magnified 60 diameters.

A dozen or more funiculi of various sizes are included in the photograph. The fat-cells in the epineurium appear as clear spaces.

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[1] This term has been introduced by Langley to include both the nerves of the sympathetic system and the analogous nerves which proceed from the cranial and sacral regions for the innervation of certain involuntary muscles and secreting glands.

they are beset with numerous nuclei which have usually been regarded as belonging to a delicate sheath, although, as a matter of fact, both in longitudinal view and in cross section the nuclei appear to lie in the substance of the fibres rather than at their surface. The sympathetic nerves, as they approach their peripheral distribution, are largely made up of fibres of this nature, but the preganglionic fibres, both of sympathetic and of other autonomic nerves, always possess a thin medullary sheath, and have the usual structure of medullated fibres.

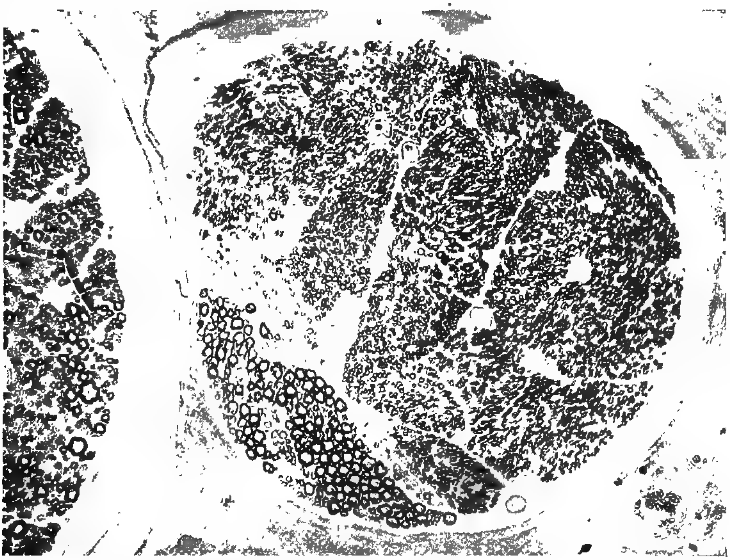
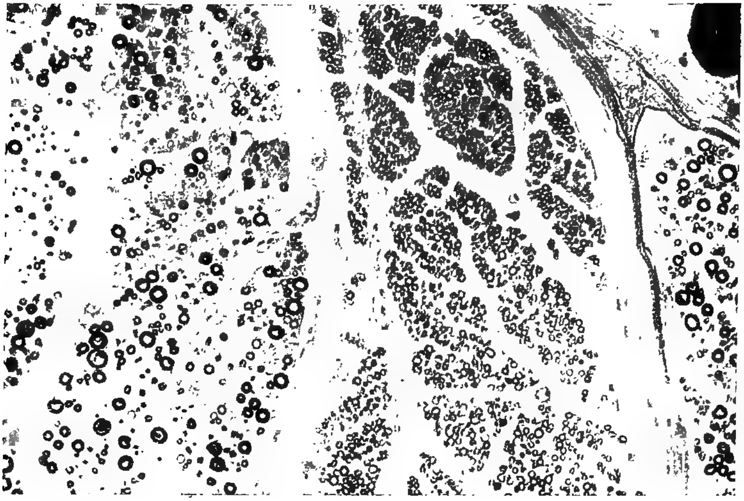


FIG. 208.—SECTION OF THE CERVICAL SYMPATHETIC OF THE CAT. Photographed from an osmic preparation made by R. Tsukaguchi. Magnified 200 diameters. On the left a small portion of the vagus is seen.

The vagus and sympathetic in the neck of the cat run in separate perineural sheaths, but are united by epineurium. The vagus has both moderately large and fine medullated fibres and also a considerable number of non-medullated fibres. The sympathetic nerve is mainly composed of fine medullated fibres derived from the thoracic anterior roots. In this case the sympathetic includes a bundle of large medullated fibres derived from the vagus higher up.

Structure of the nerve-trunks.—In their course through the body the nerve-fibres are gathered up into *bundles* or *funiculi*, and the funiculi are again united together to form the nerves which we meet with in dissection (fig. 207). The connective tissue which unites the funiculi and invests the whole nerve, uniting it to neighbouring parts and conveying to it blood-vessels, lymphatics, and even nerve-fibres destined for its coats, is termed the *epineurium*; it frequently contains fat-cells. That which ensheathes the funiculi is known as the *perineurium*. It has a distinctly lamellar structure, the lamellæ being composed of connective tissue covered by flattened epithelioid cells (fig 210, A). Between the lamellæ are clefts for the conveyance of lymph from the interior of the funiculus to the lymphatics



Vagus. *Sympathetic.*

FIG. 209.—SECTION OF VAGO-SYMPATHETIC NERVE OF DOG INCLUDING A PORTION OF EACH NERVE. Photographed from an osmic stained preparation made by R. Tsukaguchi. Magnified 200 diameters.

In the dog the vagus and sympathetic in the neck are included in one perineural sheath: their fibres are only separated by a septum of endoneurium.

of the epineurium. The delicate connective tissue which lies between the nerve-fibres of the funiculus is the *endoneurium*. It assists in supporting

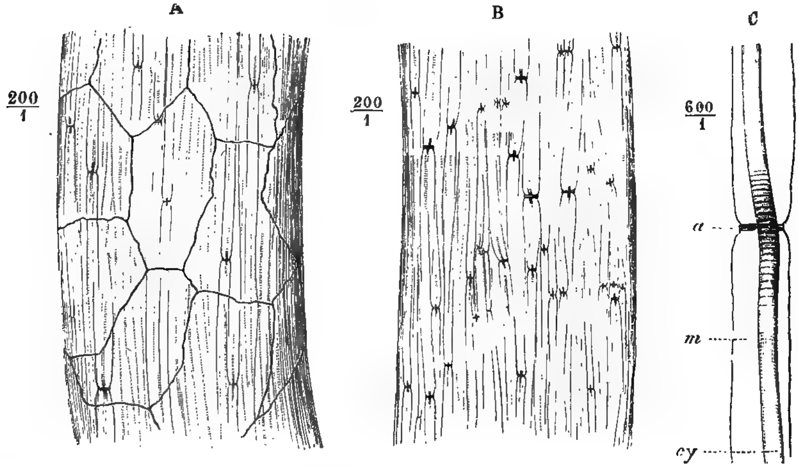


FIG. 210.—NERVES STAINED WITH SILVER NITRATE. (Ranvier.)

In *A*, the epithelial-like layer of flattened cells belonging to the sheath of Henle is stained. In *A* and *B*, the cross-like markings at the nodes are exhibited. In *C*, a single fibre is shown more highly magnified, with Frommann's transverse markings of the axis-cylinder. *a*, constricting band; *m*, medullary sheath; *cy*, axis-cylinder.

the longitudinally arranged meshwork of blood-capillaries, and its interstices communicate with the lymph-clefts of the perineurium.

All the branches of a nerve, and even single nerve-fibres which are passing to their distribution, are invested with a prolongation of the perineural sheath, which is then known as the *sheath of Henle.*

The nerve trunks themselves receive sensory nerve-fibres (*nervi nervorum*) which ramify chiefly in the epineurium and terminate within this in end-bulbs (Horsley).

The degenerative processes which occur in cut nerve-fibres as well as the subsequent reparative processes are dependent on the nerve cells from which the fibres take origin and will be dealt with after the structure of nerve-cells has been studied (see p. 174).

LESSONS XVII. AND XVIII.

THE TISSUES OF THE NERVOUS SYSTEM (*continued*).

1. Put a small fragment of spinal ganglion of frog or mammal into 1 per cent. osmic acid for a few hours. Place in water containing a fragment of thymol for two days or more. Tease in dilute glycerine. Notice the spheroidal ganglion-cells; their large nuclei and distinct nucleoli. Many of the cells may still be seen within their nucleated membranous sheath. Look for cells which still retain the axis-cylinder process and for T-shaped junctions of nerve-fibres with this. Fat-cells may be present in the periganglionic connective tissue. These will appear intensely black in osmic preparations.

2. Prepare in the same way a spinal ganglion or the Gasserian ganglion of the skate or cod. Notice the bipolar character of most of the cells.

3. Prepare a piece of sympathetic ganglion as in §§ 1 and 2. If from the rabbit observe that many of the cells are bi-nucleated.

Measure two or three cells in each of the above preparations.

4. Mount stained sections of ganglia, both spinal and sympathetic. These will serve to show the arrangement of the cells and fibres in the ganglion and the nucleated sheaths around the nerve-cells.

The ganglia may be fixed and hardened in saturated solution of corrosive sublimate or of picric acid or in 10 per cent. formol. They may either be stained in bulk or sections cut from paraffin and stained on the slide.

5. Ehrlich's methylene-blue method, Golgi's silver chromate method, or Cajal's silver reduction method, especially the last named, are all useful for showing the connexions of ganglion-cells with nerve-fibres. These methods are described in the Appendix.

6. Place a portion of the grey matter from a piece of spinal cord of ox, or calf, or man, in 33 per cent. alcohol, or $\frac{1}{8}$ per cent. bichromate of potassium. After a few days a little of the tissue may be shaken up in a test-tube with water so as to break it up into fine fragments. Allow these to subside, decant off the water and substitute a dilute solution (1 to 500) of methylene blue or a solution of picro-carmine. When it appears sufficiently stained, some of the débris is pipetted off and examined under a low power of the microscope; at first without a cover-glass so that the cells may, if necessary, be separated with needles from the rest of the tissue. Mount in water with a short piece of hair under the cover-glass. Notice the large branching cells, some with a mass of pigment near the nucleus. Observe the fibrillation of the cell-processes. Many axis-cylinders will be seen in this preparation deprived wholly or partially of their medullary sheath, and their fibrillar structure can then also be well seen. Carefully sketch these appearances. To keep the methylene-blue preparation the stain must be fixed with picrate of ammonia, after which a mixture of glycerine and picrate of ammonia may be used for mounting. If picro-carmine is used the specimen is simply preserved in dilute glycerine. Similar preparations may be made from the grey matter of the cerebral cortex and cerebellar cortex.

7. Examine sections of spinal cord, medulla oblongata, and brain stained by methylene blue by Nissl's method (see Appendix), to exhibit the angular particles within the nerve-cells.

8. Examine sections of parts of brain, spinal cord, and ganglia prepared by Cajal's method, to exhibit the neuro-fibrils in the cells and cell-processes.

9. Examine the nerve-cells and neuroglia-cells in sections from the spinal cord, cerebrum, or cerebellum of a small animal, *e.g.* young rat or kitten, prepared by Golgi's method. The sections must be mounted in thick xylol balsam or dammar, without covering, and dried rapidly on a warm plate.

10. Examine sections of spinal cord (lumbar enlargement) and corresponding spinal ganglia from an animal in which the sciatic nerve was cut about three weeks before it was killed. The sections are to be stained by Nissl's method. Most of the anterior horn nerve-cells and of the ganglion-cells on the side of the lesion will exhibit chromatolysis (breaking down of the Nissl granules) which is characteristic of cells the axons of which have been severed. The altered cells may be compared with the normal cells on the intact side.

7, 8, 9, and 10 may be deferred until the central nervous system is studied.

STRUCTURE OF NERVE-CELLS.

Nerve-cells or neurocytes are met with in the grey matter of the nerve-centres, and in little groups on the course of certain of the peripheral nerves; these groups often causing nodular enlargements of the nerves, which are known as *ganglia.* The most conspicuous ganglia are those which are found upon the posterior roots of the spinal nerves, upon the roots of some of the cranial nerves, and upon the trunk and principal branches of the sympathetic. Minute ganglia are also found very numerously in connexion with the nerves which are supplied to glands and involuntary muscular tissue, as in the salivary glands, heart, alimentary canal, bladder, uterus, etc.

Nerve-cells vary much in size and shape; many are large, some being among the largest cells met with in the body, but others are quite small. The *cell-body* or *cyton* (Sanger Brown) is usually erroneously termed the nerve-cell; it is the part of the cell containing the nucleus. The latter is large and usually spherical and contains a very distinct nucleolus. All nerve-cells possess at least one process, the *nerve-fibre process, axon,* or *neuron,* which becomes either a non-medullated nerve-fibre or the axis-cylinder of a medullated fibre. If other processes are present they are always branched almost from their commencement at the cell-body, and they are therefore termed the *dendrites* or *dendrons.* The cytoplasm is fibrillated, the fibrils passing into all the processes; they are known as *neuro-fibrils,* and are believed to be the actual conductors of nerve-impulses. We have already noted their existence in the axis-cylinder of the nerve-fibre (p. 150). Nerve-cells contain numerous mitochondria, which can be shown by *intra vitam* stains (Cowdry). The cytoplasm also contains peculiar angular masses (*Nissl granules*) staining deeply with basic dyes such as methylene blue, but the size, number, and arrangement of these granules in different cells vary greatly (fig. 211). The Nissl granules also vary in number and size with the physiological condition of the cell; thus it is found that

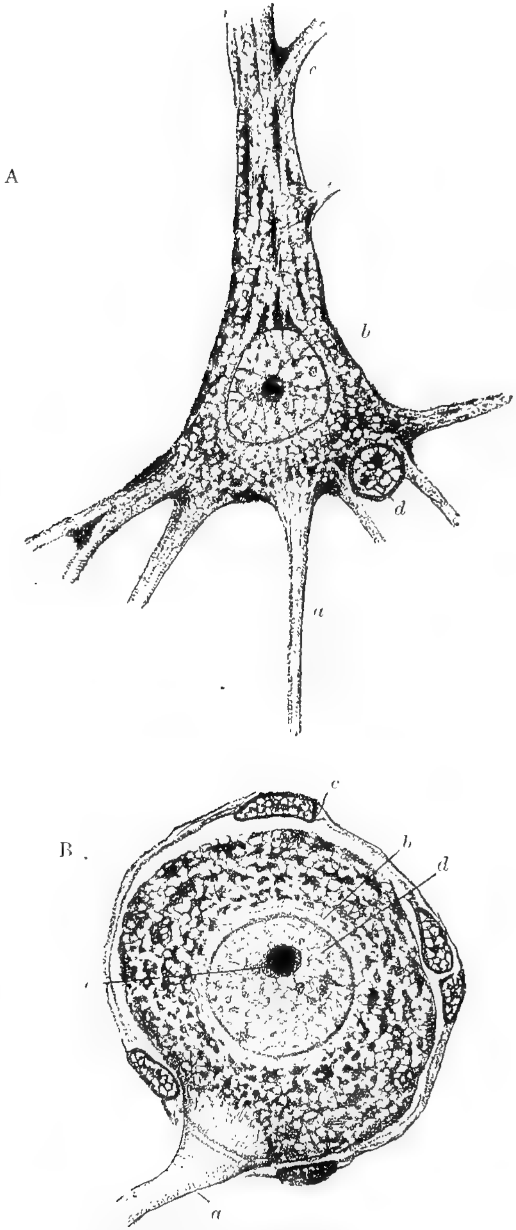


FIG. 211.—MULTIPOLAR AND UNIPOLAR TYPES OF NERVE-CELL. (Cajal.)

A, Large pyramidal cell of cerebral cortex, human. Nissl method. *a*, axon; *b*, cyton; *c*, apical dendron; *d* is placed between two of the basal dendrons and points to the nucleus of a neuroglia cell which is applied to the cyton.

B, Unipolar cell from spinal ganglion of rabbit. Nissl method. *a*, axon; *b*, circumnuclear zone, poor in granules; *c*, capsule; *d*, network within nucleus; *e*, nucleolus.

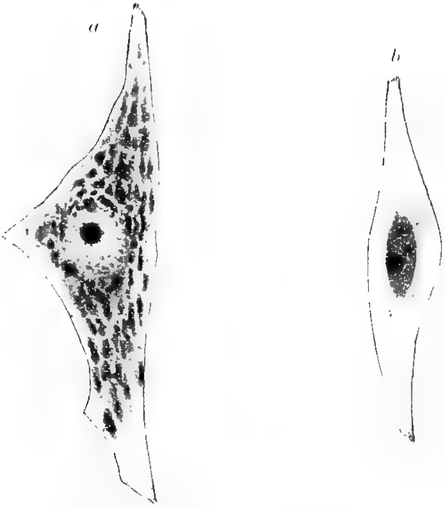


FIG. 212.—TWO MOTOR NERVE CELLS FROM THE DOG.

a, normal; *b*, after a period of prolonged activity. (Photographed from preparations by G. Mann.)

nerve cells which have been fatigued by prolonged activity (fig. 212), and also those the axis-cylinder process of which has been cut (fig. 213),

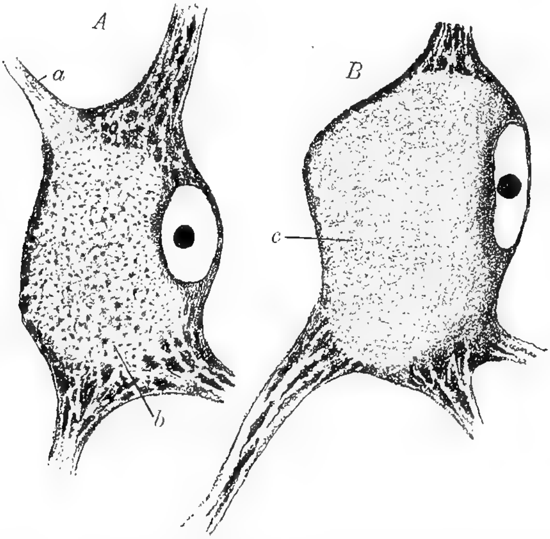


FIG. 213. CHROMATOLYSIS OF TWO NERVE-CELLS OF SPINAL CORD OF RABBIT, PRODUCED BY SEVERANCE OF MOTOR NERVE 15 DAYS PREVIOUSLY. (Cajal.)

In *A*, the chromatolysis is rather less advanced than in *B*. In both the nucleus is displaced to the periphery. ***a***, axon; *b*, *c*, chromatolysed cell-substance. A completed condition of chromatolysis is seen in fig. 212, *b*.

show the Nissl granules becoming disintegrated; they may even disappear for a time from the cell. A similar result is found to occur after the action of poisons which especially affect the nervous system. The Nissl granules of the nerve-cell appear to consist chemically mainly of nucleoprotein. They contain organically combined iron (Macallum). Many nerve-cells have a clump of pigment-granules (fig. 214), containing lecithin, at one side of the nucleus. This is especially marked in certain localities (locus cœruleus, locus niger), and is more frequent in man than in the lower animals. The pigment tends to increase in amount as age advances. As already stated, the cyton or body of every nerve-cell is traversed by fine fibrils (*neuro-fibrils*) continuous with those in the axis-cylinder of the issuing nerve-fibre process and with similar fibrils in the dendritic processes. They were noticed by Max Schultze in vertebrates and were later described by Apáthy in certain annelids. They can be seen without difficulty in all nerve-cells (fig. 215) by the employment of certain special methods of staining. The neuro-fibrils are said to present variations in thickness according to the condition of activity of the cell at the time of death.

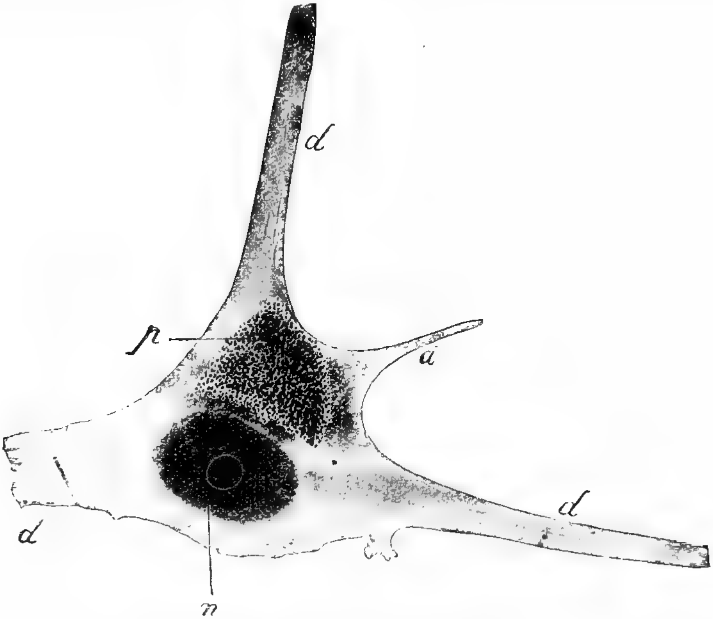


FIG. 214.– A NERVE-CELL FROM THE HUMAN SPINAL CORD. (From Prenant, Bouin, and Maillard.)

a, axon ; *d*, dendrons ; nucleus with nucleolus ; *p*, pigment-granules.

Most, if not all, nerve-cells show a delicate *superficial reticulum* (fig. 216), described by Golgi, which, according to J. Turner, is an investment derived from neuroglia-cells. Golgi has also described another network of fibrils with somewhat larger meshes (*deep reticulum* of Golgi) (fig. 217) in the deeper parts of the cell. The meaning of this network is not known. Although most distinct in nerve-cells it is not confined to them, a similar network having been noticed in a variety of epithelial and other cells.

Entirely distinct from the nerve-fibrils is a system of fine canaliculi, which has been described by E. Holmgren, permeating the cytoplasm of the cell-body in some nerve-cells for the purpose of subserving its nutrition by conveying plasma into its substance (fig. 218). These channels are believed by Holmgren to be quite distinct from the deep reticulum of Golgi. He describes them as occupied by branching processes of neuroglia-cells (*trophospongium*). In the very large nerve-cells from which the nerves to the electric organs of Malapterurus arise, even blood-vessels penetrate into the cytoplasm.

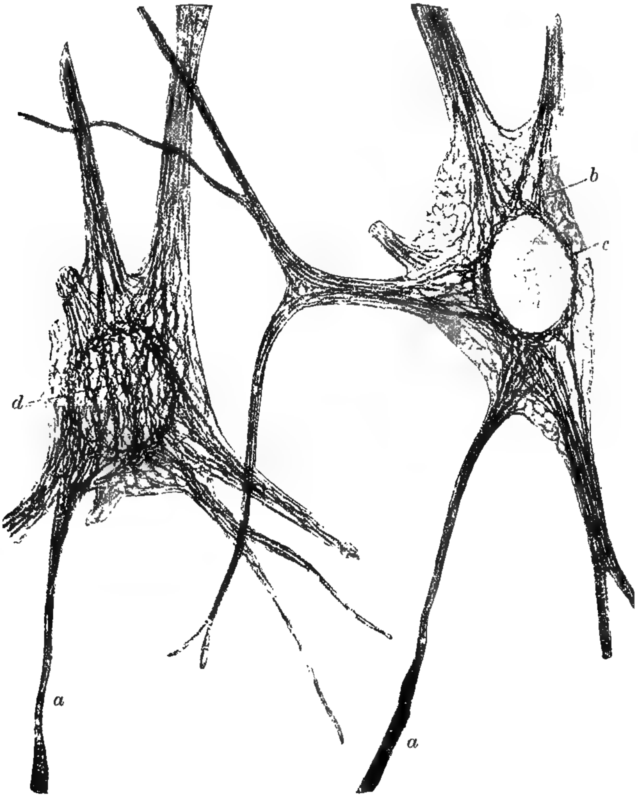


FIG. 215.—NERVE-CELLS OF KITTEN (FROM THE ANTERIOR CORPORA QUADRIGEMINA) SHOWING NEURO-FIBRILS. (Cajal.)

a, axon ; *b*, *c*, *d*, various parts of the intracellular plexus of fibrils.

Processes of nerve-cells.—As already intimated, the processes are of two kinds. The first is that known as the *axis-cylinder process* (Deiters) or *nerve-fibre process*, so called because in medullated nerve-fibres it becomes

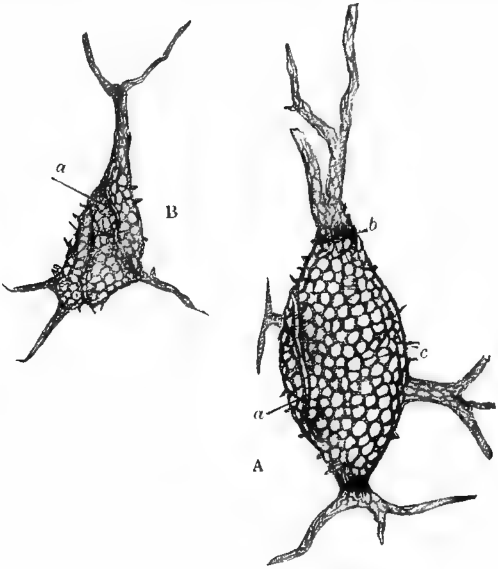


Fig. 216.—Superficial network of Golgi surrounding two cells from the cerebral cortex of the cat: Ehrlich's method. (Cajal.)

A, Large cell; *B*, small cell. *a*, *a*, folds in the network; *b*, a ring-like condensation of the network at the poles of the larger cell; *c*, spinous projections from the surface.

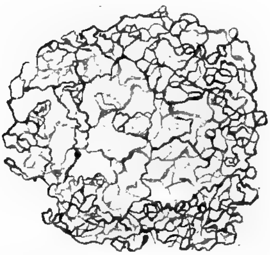


Fig. 217.—Nerve-cell from spinal ganglion, showing network around the nucleus. (Golgi.)

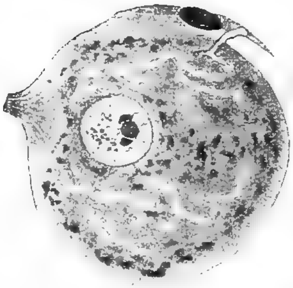


Fig. 218.—Trophospongium within a ganglion-cell. (E. Holmgren.)

the axis cylinder (fig. 219, *a*, *a'*); in non-medullated fibres, it becomes the nerve-fibre itself. It is usually known as the *axon* or *neuraxon*, although the term *neuron*[1] better expresses the fact that it is the nerve-fibre.

No fully developed nerve-cell is without this process. The place where it arises from the body of the nerve-cell (*cone of origin*) is marked off from the rest of the cell-substance by absence of Nissl granules (see fig. 211). The other processes of the nerve-cell are those which were termed by Deiters the *protoplasmic processes*; they are now usually termed the *dendritic processes*, *dendrons*, or *dendrites*, and are generally multiple, whereas the axon is generally single. The dendrons are characterised by the fact that as soon as they leave the cell they begin to ramify like the roots of a tree, whereas the axis-cylinder process does not branch until near its termination, with the exception of a few fine lateral offshoots (*collaterals*), which are sometimes given off in its course. Dendrons may be altogether absent; the cell is then *adendritic*. Some nerve-cells have only one process (*unipolar cells*), but most have two or more (*bipolar*, *multipolar*). The dendrons contain Nissl granules, but the axons never.

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[1] From the greek word νεῦρον, a nerve.

The shape of the cell-body depends largely on the number of processes and the manner in which they come off. If there is but one chief process the cell (cell-body) is generally nearly spherical. This is the case with most of the cells of the spinal ganglia (fig. 211, B); in these the single process, after a short course, divides into two fibres, which pass the one centrally the other peripherally (fig. 230). When there are two main processes from a nerve-cell they often go off in opposite directions from the cell, which is thus rendered somewhat spindle-shaped (fig. 220), but occasionally they emerge at the same part. When there are three or more processes, the cell becomes irregularly angular, as in the motor-cells of the spinal cord and the pyramidal cells of the cerebral cortex (fig. 211, A; fig. 214).

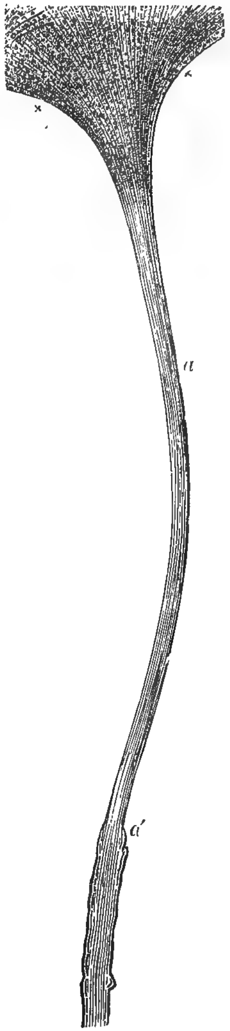

FIG. 219.—AXIS-CYLINDER PROCESS OF A NERVE-CELL FROM THE SPINAL CORD. (M. Schultze.)

× ×, portion of the cell-body, out of which the fibrils of the axis-cylinder process, *a*, are seen to emerge. At *a′*, this process acquires a medullary sheath. Highly magnified.

In some cases where there appear to be two fibres connected with a cell, one of them is derived from another nerve-cell elsewhere, and is passing to end in a ramification which envelopes the cell-body. In certain situations the ramification is coarse and forms a calyx-like investment to the cell-body (fig. 221); in other places the pericellular fibrils are very fine and form a fine arborisation over the cell-body. Where the fibrils come in contact with the surface of the cell they may end in small button-like enlargements or varicosities (fig. 222).

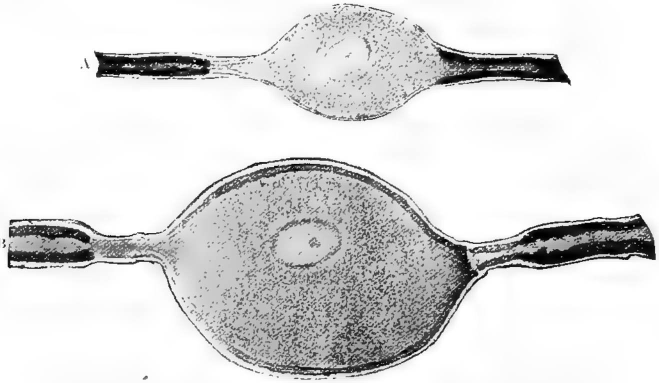

FIG. 220. TWO BIPOLAR GANGLION-CELLS OF FISH. (Holmgren.)
In *A*, the medullary sheath stops short of the cell-body; in *B*, it is continued as a thin layer over the cell-body.

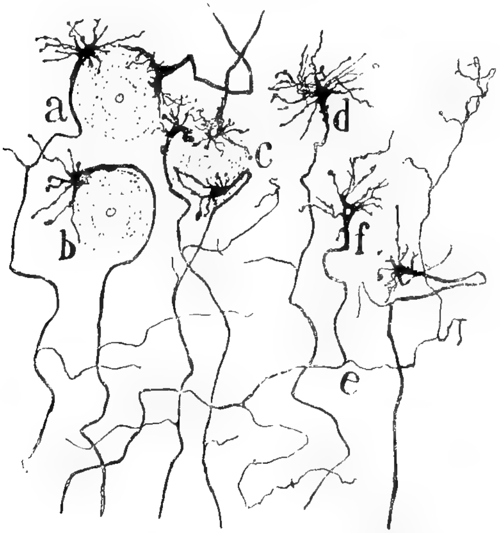

FIG. 221. PERICELLULAR ENDINGS OF NERVE-FIBRES IN THE CENTRAL ACOUSTIC NUCLEUS. (Cajal.)
In *a*, *b*, and *c*, the cell-bodies around which the ends of the fibres form synapses are indicated: in *d*, *e*, and *f* they are omitted.

In preparations made by Golgi's chromate of silver method the nerve-cells and their processes are coloured black by a deposit of reduced silver, so that the processes can be traced for a considerable distance from the body of the cell, in fact in many instances as far as their remotest ramifications.

It has been found by the employment of this method that the axis-cylinder process is not always an unbranched process, as was formerly supposed, but that it usually, if not invariably, gives off fine lateral branches (*collaterals*), which themselves tend to ramify in the adjacent nerve-substance (fig. 223, *c*). And although the main part of the axon process usually passes on and becomes the axis-cylinder of a long medullated nerve-fibre (*long-axoned cell*, fig. 223), this is not always the case, for in another type of nerve-cell within the nerve-centres (*short-axoned cell*, fig. 224), the axis-cylinder process breaks up almost immediately into an arborescence. The long process of the first type (which becomes the axis-cylinder of a long nerve-fibre), although it may remain unbranched throughout its course, ultimately ends in almost every instance in a terminal ramification or arborescence; whether the ending be at the periphery or within the central nervous system itself.

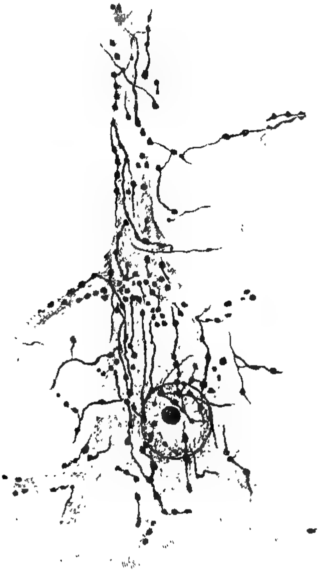

FIG. 222.—PERICELLULAR NEURO-FIBRILS AROUND A LARGE PYRAMIDAL CELL OF THE HUMAN CORTEX CEREBRI.

I am indebted to Dr J. Turner for the drawing here reproduced.

Synapses.—Each nerve-cell including all its processes is regarded as an anatomically independent element (*nerve-unit*, *neurone*, *neurocyte*), and the connexion of one nerve-cell with another is believed to be effected through the medium of the terminal arborisations of the cell-processes. Such arborisations, derived from different cells, may interlace with one another, as in the olfactory glomeruli, in the retina, and in the sympathetic ganglia (fig. 225); or a terminal arborisation from one cell may embrace the body or the cell-processes of another cell; as with the cells of the spinal cord (fig. 226),

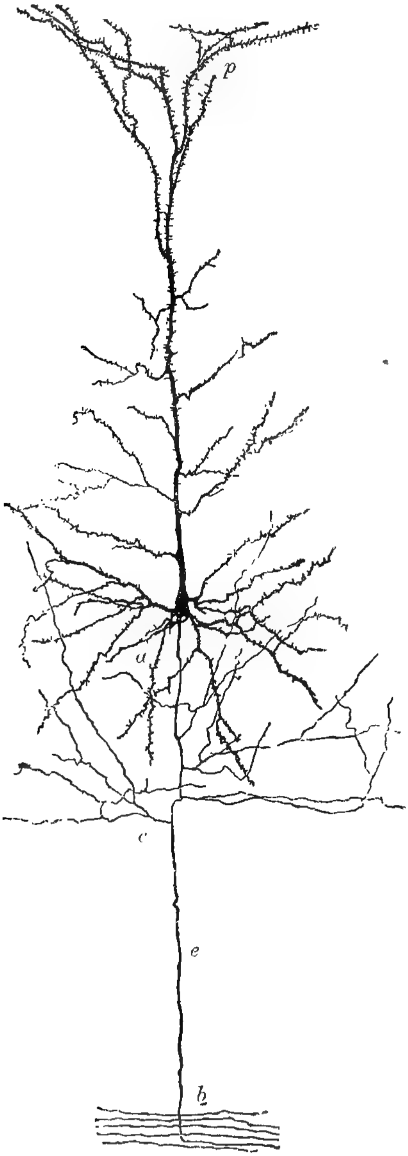

Fig. 223.—A PYRAMIDAL CELL OF THE CORTEX CEREBRI OF THE RABBIT. CELL OF TYPE I. OF GOLGI (WITH LONG AXON). (Cajal.)

a, basal dendrons; *p*, apical dendron ramifying near surface; *e*, axon or nerve-fibre process; *c*, its collaterals; *b*, fibres of white matter of brain.

the cells of the central acoustic nucleus in the pons (fig. 221) and in many other places. The term *synapse* or *neuro-synapse* is applied to these modes

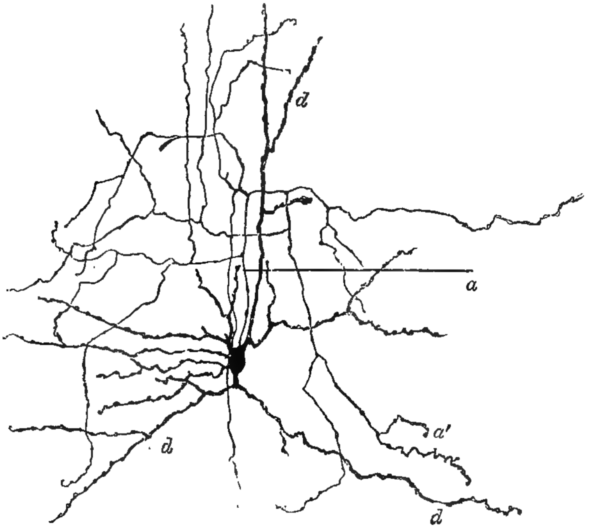

FIG. 224.—CELL OF TYPE II. OF GOLGI, WITH SHORT AXON RAMIFYING IN THE ADJACENT GREY MATTER. GOLGI METHOD. (Cajal.)
a, axon ; *d*, *d*, dendrons.

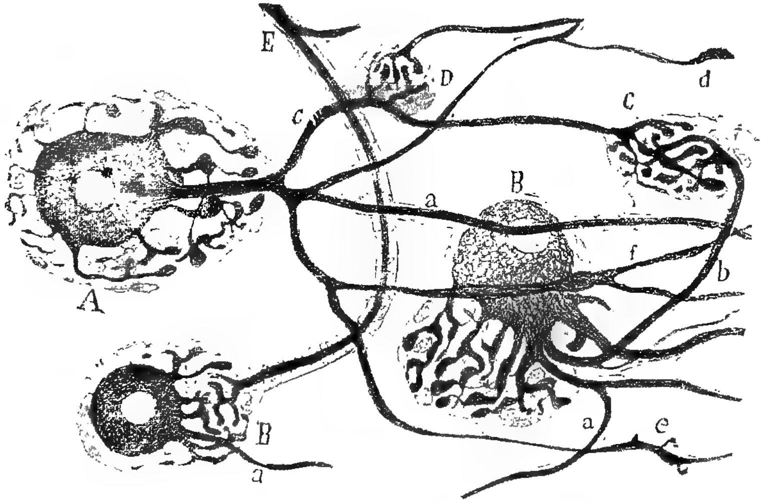

FIG. 225.—SYNAPTIC CONNEXIONS OF SYMPATHETIC CELLS FROM THE SUPERIOR CERVICAL GANGLION OF MAN. (Cajal.)
The cells *A*, *B* show well-marked intracapsular dendrons ; *C*, *D*, synapses between dendrons outside the cell-capsules ; *E*, a fibre, which is itself surrounded by a fine spirally wound fibril, passing to a cell and forming a synapse with the cell dendrons within the capsule ; *a*, *a*, axons ; *b*, *c*, *d*, *e*, *f*, extra-capsular dendrons.

of junction. By them nerve-cells are linked together into long *chains of* *neurones*; the anatomical path, as above indicated, being interrupted at the synapses, although physiological changes (nerve impulses) are propagated—stepping over, as it were, from one neurone to the other at each synapse. Probably what really happens is a generation of new nervous impulses in the successive neurones of the chain.

The doctrine of the anatomical independence of the nerve-cell is known as the "neurone-theory" (Waldeyer). It is supported by the appearances of chromate of silver preparations of nerve-cells. In these the reduction of the silver is strictly confined to single cells, which become stained with all their processes; and these processes, when demonstrated by this method, are never found in continuity either with the processes or with the bodies of other nerve-cells. Moreover, many of the facts relating to nerve-degeneration can be more readily interpreted by this theory than by one which assumes the existence of direct continuity between the nerve-units. But it has been shown by Apáthy that in annelids (the nervous system of which was formerly supposed to offer a typical example of isolated, linked "neurones"), the fibrils are in fact continuous from cell to cell and are not interrupted at the synapses; it is possible that the same may prove true for vertebrates also, in which case the doctrine of independent units would require modification. But there undoubtedly exists a physiological independence so far as the maintenance of nutrition of the cell (or neurone) is concerned; and there is also evidence that in the transmission of nerve impulses from one neurone to another a block always occurs at the synapses, causing a slight arrest or delay in the transmission. It is also noteworthy that nerve-impulses, so far as is known, pass a synapse in one direction only, never in the reverse direction. In motor or efferent neurones this direction is always towards the cell-body by the dendrons and away from it by the axon.

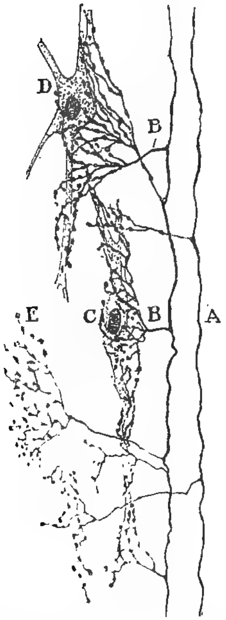

FIG. 226.—ARBORISATION OF COLLATERALS FROM THE DORSAL ROOT-FIBRES AROUND CELLS IN THE DORSAL HORN OF GREY MATTER. (Cajal.)

A, fibres of dorsal column derived from dorsal root; *B*, collaterals; *C*, *D*, nerve-cells in grey matter surrounded by the arborisations of the collaterals; *E*, an arborisation shown separately.

NERVE GANGLIA.

In the ganglia (figs. 227, 228) each nerve-cell has a nucleated sheath which is continuous with the neurolemma of the nerve-fibre with which the cell is connected. In the **spinal ganglia**, and in many of the corresponding ganglia on the roots of the cranial nerves of mammals and of most other vertebrates, the cells have only one issuing process, the axis-cylinder process, which soon acquires a medullary sheath and then passes with a somewhat convoluted course to some little distance from the cell-body, where, still within the ganglion, it divides into two; one fibre passing to the nerve-centre, and the other towards the periphery. The branching is T-shaped or

Y-shaped, and always occurs at a node of Ranvier (figs. 229, 230). The neuro-fibrils of the central and peripheral branches retain their individuality

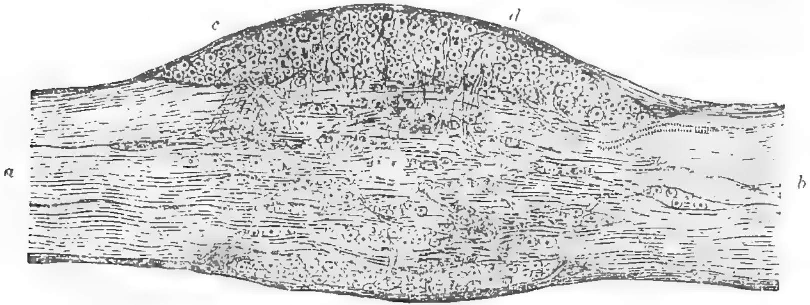

FIG. 227.—LONGITUDINAL SECTION THROUGH THE MIDDLE OF A GANGLION ON THE POSTERIOR ROOT OF ONE OF THE SACRAL NERVES OF THE DOG, AS SEEN UNDER A LOW MAGNIFYING POWER.

a, nerve-root entering the ganglion ; *b*, fibres leaving the ganglion to join the mixed spinal nerve ; *c*, connective-tissue coat of the ganglion ; *d*, principal group of nerve-cells, with fibres passing down from the cells, to unite with the longitudinally coursing nerve-fibres by **T**-shaped junctions.

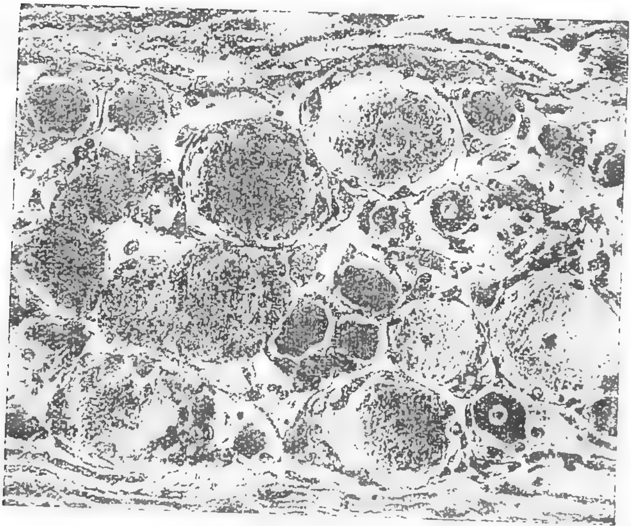

FIG. 228.—FROM A SECTION OF DOG'S SPINAL GANGLION, SHOWING DIFFERENT TYPES OF CELLS. Photograph. Magnified 240 diameters.

The clear patch, free of Nissl granules, seen in some of the cells is the place of origin of the axon. Some of the cell bodies have shrunk away from the nucleated capsule. Notice the smaller and more darkly staining cells, contrasting with the larger and clearer cells.

in the common trunk ; they are traceable into a neuro-fibril network within the cell-body (fig. 254). These spinal ganglion-cells have, as a rule, no dendrons, but some show, besides the axon, short processes terminating in bulbous enlargements (fig. 232) either within the cell-capsule or immediately

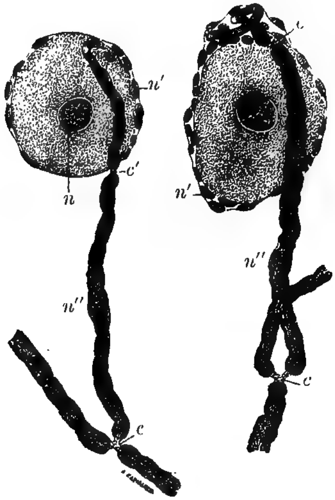

Fig. 229.—Two spinal ganglion-cells, showing bifurcation of their nerve-fibre processes. (Ranvier.) Osmic preparation.

n, nucleus of one of the cells; n', nuclei of capsules; n'', nuclei of neurolemma; c, c, c' c', constrictions of Ranvier.

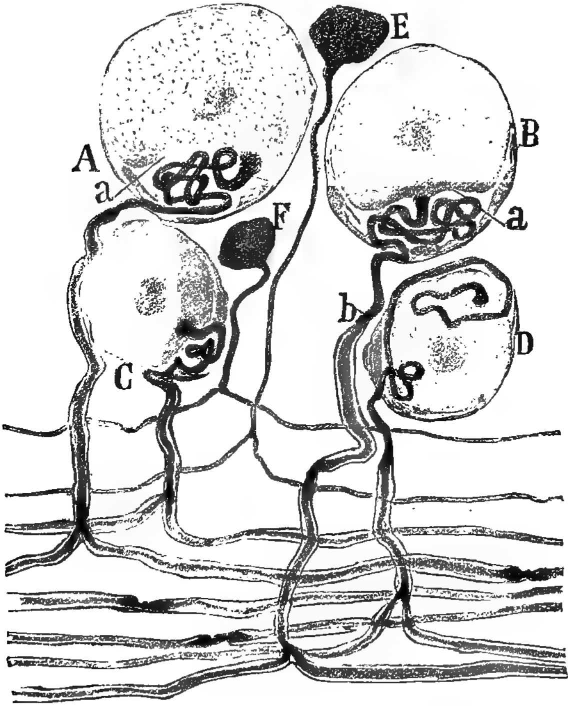

Fig. 230.—Types of cerebro-spinal ganglion-cells, from vagus ganglion of cat. (Cajal.)

A, *B*, large cells with much convoluted commencement of axon; *C*, *D*, smaller cells; *E*, *F*, smallest cells, staining darkly and without axonal convolution.

outside it (Huber, Cajal). These either represent dendrons, or, as Nageotti has suggested, aborted axons. Short intracapsular processes also occur in sympathetic ganglia (figs. 225, 236).

The origin of the axon is not always simple, but may be multiple, the several parts forming at first a plexus close to the cell, eventually joining to produce a single axon. According to Cajal this multiple condition tends to become accentuated with age (fig. 233).

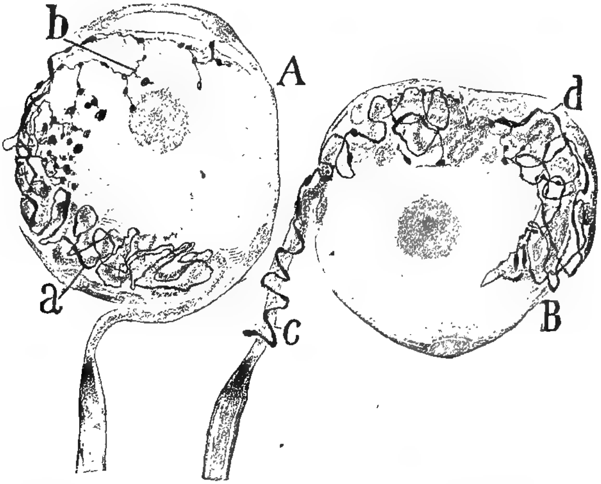

Fig. 231.—Pericellular arborisations in spinal ganglion-cells. (Cajal.)
In *A* the arborisation extends over the cell-body; in *B*, it is limited to the axon. *a*, *b*, *c*, *d*, afferent fibre.

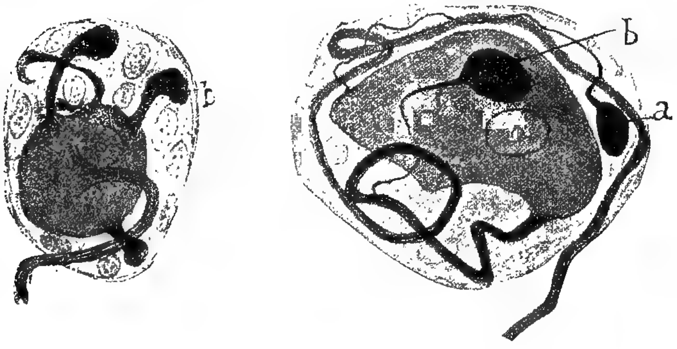

Fig. 232.—Cerebro-spinal ganglion-cells, man. (Cajal.)
a, *b*, intracapsular dendrons, with knobbed extremities.

Two chief varieties of cell occur in the spinal ganglia, one large and clear, the other small and staining almost uniformly dark (figs. 228, 230). According to Rawson, the latter give origin to non-medullated sensory nerve-fibres. The cell-body of the spinal ganglion-cell is sometimes invested by ramifications of a fine nerve-fibre (fig. 231), derived either from one of the other cells of the same ganglion or from a cell in a neighbouring sympathetic ganglion. Similar fibres, forming pericellular plexuses, also occur in sympathetic ganglia (fig. 237).

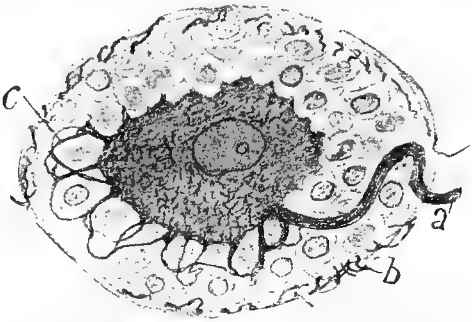

FIG. 233.—SENILE TYPE OF CEREBRO-SPINAL GANGLION-CELL. (Cajal.)
a, issuing axon ; *b*, part of pericellular plexus ; *c*, pericellular loops.

Sections of **sympathetic ganglia** (fig. 234) do not show the regular arrangement of large bundles of medullated fibres traversing the ganglion which forms a conspicuous feature in spinal ganglia. The nerve-cells are smaller; they usually have several dendrons and one axon; this generally becomes a non-medullated nerve-fibre, but is occasionally finely medullated. In certain animals (rabbit, hare, guinea-pig) the sympathetic cells have each two nuclei (fig. 235). In the frog the sympathetic cells are unipolar, but

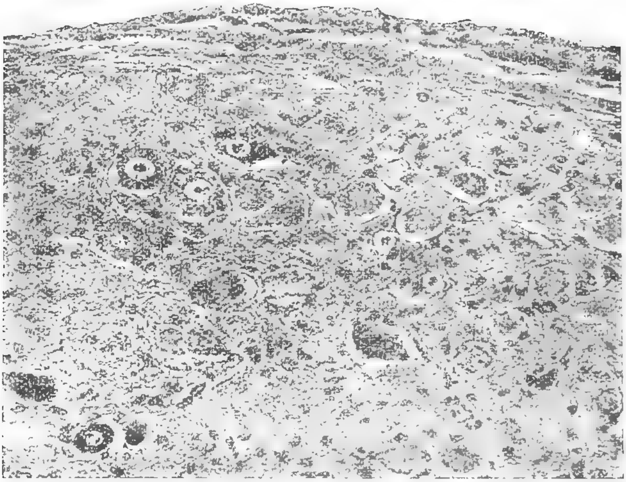

FIG. 234.—SECTION OF SYMPATHETIC GANGLION OF DOG. Photograph. Magnified 240 diameters.

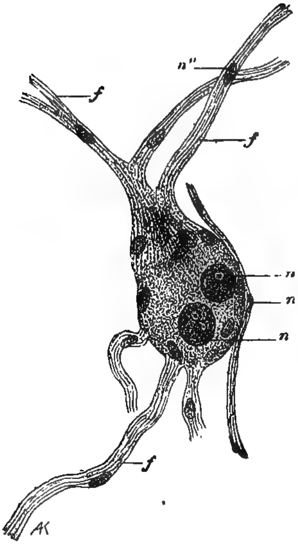

Fig. 235.—A sympathetic nerve-cell. (Ranvier.)
n, *n*, nuclei of cell; *f*, *f*, pale fibres issuing from cell; *n′*, *n″*, nuclei on fibres.

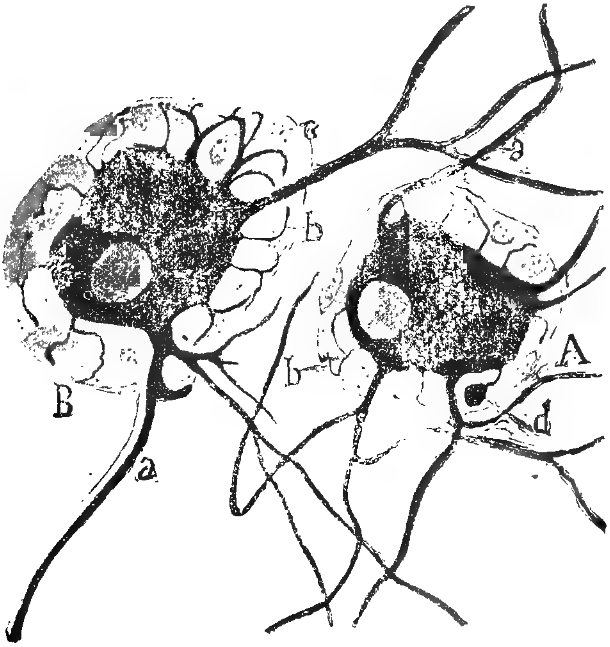

Fig. 236.—Two sympathetic ganglion-cells, man. (Cajal.)
a, *a*, axon; *b*, *c*, intracapsular processes; *d*, knob-like ending of an intracapsular process.

sometimes with a second spiral fibre winding round the issuing axon. Such spiral fibres occur also in man; here they appear to be afferent fibres which are forming synapses around the axons and cell-bodies of the ganglion-cells (fig. 237).

The cells of ganglia are disposed in aggregations of different size, separated by bundles of nerve-fibres (fig. 234). The ganglion if large is enclosed by an investing capsule of connective tissue which is continuous with the epineurium and perineurium of the entering and issuing nerve-trunks.

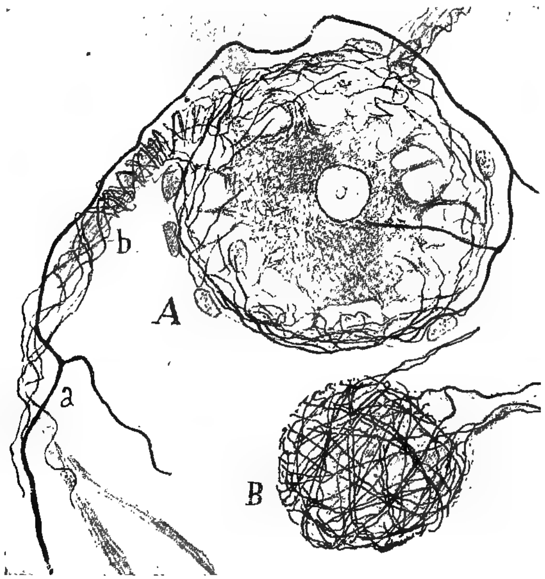

FIG. 237.—TWO CELLS FROM A SYMPATHETIC GANGLION OF MAN SHOWING THE TERMINATION OF AFFERENT FIBRES WITHIN THE CELL-CAPSULE. (Cajal.)

A, large; *B*, small cell. *a*, *b*, afferent fibres surrounding a dendron and passing into the capsule.

DEGENERATION AND REGENERATION OF NERVE-FIBRES AND NERVE-CELLS.

Degeneration.—Since each nerve-fibre is the process of a nerve-cell, when a nerve is cut, the separated part degenerates. Its axis-cylinder becomes broken up and disappears, the nuclei of the neurolemma multiply, and the medullary sheath undergoes a process of disintegration into droplets of fatty substance which stain intensely, like olein, in a solution of bichromate of potassium and osmic acid, a mixture which does not stain the medullary sheath of normal fibres. The change which results in the fibres was described by A. Waller in 1850, and is known as *Wallerian degeneration* (fig. 238, A to C). In man and mammals these changes begin 24 to 28 hours after section of the nerve, and proceed rapidly, so that by the third day the nerve-fibres cease to conduct impulses. When a peripheral nerve is cut, all the nerve-fibres distal to the point of section must degenerate, because all have grown from and are processes of nerve-cells in or near the nerve-centre—the afferent fibres from the cells of the ganglion on the dorsal root, the efferent fibres from the cells of the ventral horn of the spinal cord or from similar cells in the brain.

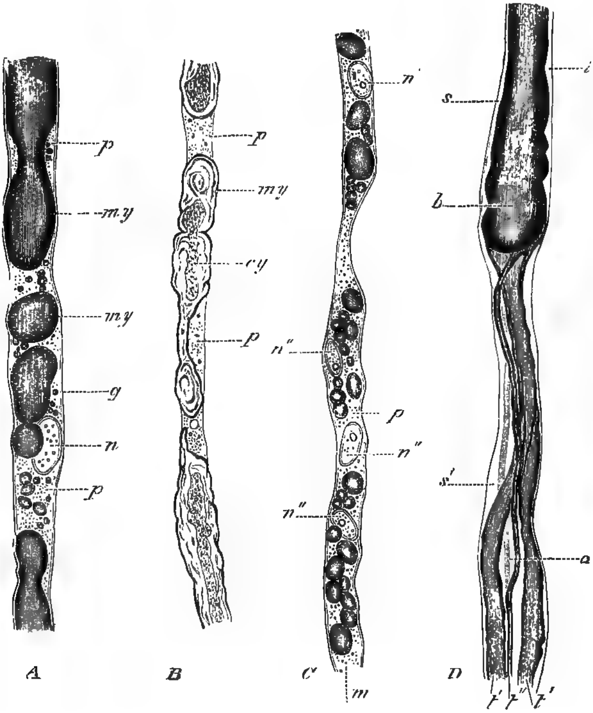

FIG. 238.—DEGENERATION AND REGENERATION OF NERVE-FIBRES IN THE RABBIT. (Ranvier.)

A, part of a nerve-fibre in which degeneration has commenced in consequence of the section, fifty hours previously, of the trunk of the nerve higher up; *my*, myelin of medullary sheath becoming broken up into drops; *p*, granular protoplasmic substance which is replacing the myelin; *n*, nucleus; *g*, neurolemma. *B*, another fibre in which degeneration is proceeding, the nerve having been cut four days previously; *p*, as before; *cy*, axis-cylinder partly broken up, and the pieces enclosed in portions of myelin, *my*. *C*, more advanced stage of degeneration, the medullary sheath having almost disappeared, and being replaced by protoplasm, *p*, in which, besides drops of fatty substance, *m*, are numerous nuclei, *n''*, which have resulted from the division of the single nucleus of the internode. *D*, commencing regeneration of a nerve-fibre. Several small fibres, *t'*, *t'*, have sprouted from the somewhat bulbous cut end, *b*, of the original fibre, *t*; *a*, an axis-cylinder which has not yet acquired its medullary sheath; *s*, *s'*, neurolemma of the original fibre. *A*, *C*, and *D* are from osmic preparations; *B*, from an alcohol and carmine preparation.

Waller supposed that no changes are produced centrally to the injury when a nerve is cut, nor indeed is there any obvious immediate alteration in the nerve-fibre itself between the place of injury and the cell-body. But it was found by Nissl that degenerative changes occur in the cell-body of every cell (whether motor or sensory) the axis-cylinder of which has been severed.[1] These changes become apparent a few days after section of the nerve-fibre and consist in a disintegration of the Nissl granules, associated at first with a general swelling of the cell-body and nucleus, which last passes to the periphery of the cell-body. After a time the disintegrated chromatic substance becomes in great measure removed and the cell-body and nucleus become shrunken in volume. This process of disintegration and disappearance of chromatin is termed *Nissl degeneration* or *chromatolysis.* It is brought about not only by section of the axon (fig. 213), but also as the result of excessive fatigue of the intact cell (fig. 212), and of the action of a large number of drugs and poisons.

The chromatolysis may be persistent or may be recovered from. Sometimes it is followed by almost complete atrophy of the cell-body, and when this is marked there may ultimately ensue a secondary Wallerian degeneration of the part of the nerve-fibre still attached to the cell. The chromatolysis is said to be accompanied by degenerative changes in the neuro-fibrils (Marinesco).

Regeneration.—After a certain lapse of time, especially if the cut ends of the nerve are left in apposition, functional continuity between them may become re-established. But when such regeneration takes place in a cut nerve, it is effected not by a re-establishment of anatomical connexion between the degenerated fibres and the fibres of the central stump, but by an outgrowth of new fibres from the stump (figs. 238, D, 239, 240), which endeavour to find their way to the periphery along the course of the degenerated fibres. If they succeed in doing so, the continuity and conducting power of the nerve become ultimately restored. This may not happen for three months or more, according to the length of nerve cut off and the nature of the severance, although the process of down-growth begins within a few hours of the injury. Some investigators have attempted to show that regeneration may take place independently in the peripheral part of the cut nerve, but the evidence offered is not conclusive, although certain changes take place there: such as the multiplication of nuclei and their regular arrangement within in long protoplasmic strands (probably in most cases occupying the old sheaths) into which the new fibres grow (fig. 241). But there is no actual union of the down-growing fibres of the central stump with others formed independently in the peripheral severed trunk, and of course no union with the old axis-cylinders, which have wholly disappeared. Recent investigations have shown conclusively that whenever continuity is re-established it is invariably due to the growth of fibres from the central stump. These down-growing fibres are usually terminated by a bulbous swelling similar to that which characterises the growing fibres of the embryonic nerves (*incre-*

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[1] But section of the dorsal root-fibres central to the ganglia does not entail degeneration of the ganglion-cells from which they arise. Nor does section of a spinal nerve always entail degeneration of the ventral horn cells from which its motor fibres arise (Van Gehuchten). Why these apparent exceptions occur is not understood.

mental cone), and they may also exhibit lateral ramifications. Even when the cut central stump is turned backwards and fixed amongst the muscles or under the skin, a certain number of newly-budded fibres may find their way from it into the degenerated peripheral part of the nerve.

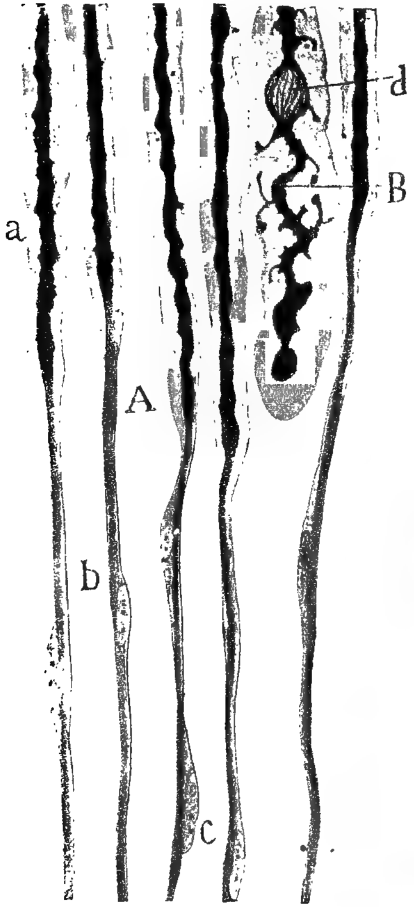

Fig. 239.—Fibres from the central cut end of sciatic nerve (of young rabbit) cut 10 days before death. (Cajal.)

A, down-growth of non-medullated fibres from the old axons; *a*, intact part still myelinated. *B*, a fibre, the axis-cylinder of which has not grown down with the rest, but which shows peculiar degenerative appearances, such as buds from the axis-cylinder, and at *d* a separation of the neuro-fibrils.

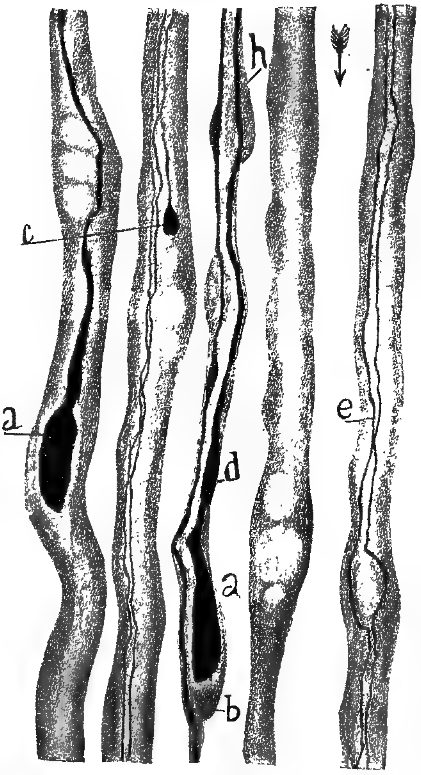

Fig. 240.—From the distal end of a nerve cut 78 days before death. (Cajal.)

Axis-cylinder sprouts which have grown down from the central cut end of a nerve into the old sheaths of the nerve-fibres; myelin drops are still visible within the old sheaths. Some of the new fibres are interstitial (not in old sheaths), they are growing in a newly formed nucleated protoplasmic strand, *h*, *b*. Two of the down-growing fibres (*a*, *a*) show enlarged ends; *c*, a neuro-fibril with bulbous enlargement; *e*, neuro-fibrils growing down within an old sheath; to the left of it, an old sheath without new fibres.

If regeneration fail to establish itself, the central end of the cut fibre and the cell-body from which it takes origin undergo slow atrophic changes resulting from disuse. These atrophic changes may ultimately extend to other links in the cell-chain, especially in young animals; so that even remote cells in the same physiological path may eventually become atrophied (*v. Gudden's atrophy, recurrent atrophy*).

No effective regeneration of cut nerve-fibres is ever seen in the brain or spinal cord, although the process of degeneration of all the fibres which are cut off from their cell-bodies occurs in the same manner as at the periphery; Nissl degeneration also takes place in the cell-bodies. Both in the nerve-centres and the peripheral nerves (if regeneration fail to occur in the latter), the place of the degenerated nerve-fibres becomes eventually occupied by strands of fine fibres, not unlike the fibres of cicatricial tissue. These strands stain deeply with carmine and remain unstained by osmic acid and by the Weigert-

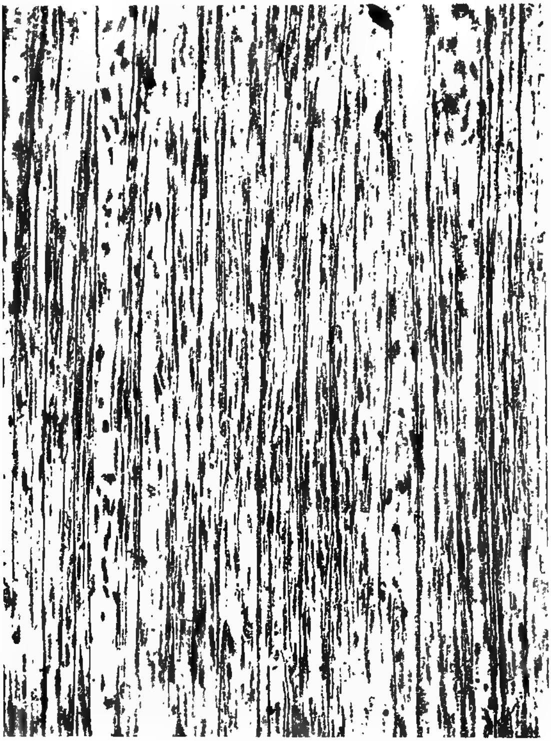

FIG. 241.—LONGITUDINAL SECTION OF THE PERIPHERAL PART OF A NERVE (CERVICAL SYMPATHETIC OF CAT) WHICH WAS CUT 42 DAYS BEFORE DEATH. (Tsukaguchi.) Magnified 200 diameters.

Notice the numerous longitudinally arranged nuclei which are embedded in protoplasmic strands. Into some of these strands neuro-fibrils from the central stump have already made their way.

Pal method, and are thus differentiated from the surrounding normal medullated nerves.

NEUROGLIA.

Besides the nerve-cells and nerve-fibres in the brain and spinal cord there occurs a peculiar tissue which has been termed the *neuroglia.* It is composed of cells and fibres, the latter being prolonged from and through the cells. Of the neuroglia-elements some are radially disposed. These start from the lining layer of the central canal of the spinal cord and the ventricles of the brain, being derivatives of the ciliated epithelium cells lining those cavities. They course in a radial direction, slightly diverging as they proceed, and constantly branching, towards the surface of the organ, where they end in enlargements attached to the pia mater. Radial neuroglia cells and fibres are seen in the embryo before the nervous elements are fully developed (fig. 242); the cells when first distinct have been termed *spongioblasts* (His).

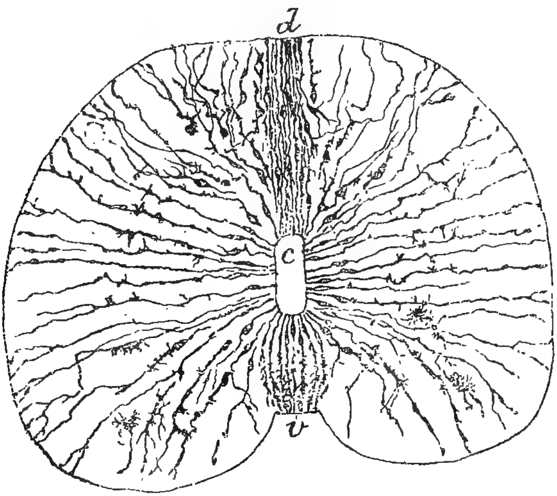

FIG. 242.—SECTION OF SPINAL CORD OF EMBRYO CHICK, SHOWING NEUROGLIA-FIBRES PROLONGED FROM THE EPITHELIUM OF THE CENTRAL CANAL. (Cajal.)

d, dorsal; *v*, ventral surface; *c*, central canal from which the neuroglia cells and fibres are seen to radiate to the periphery of the cord. Some detached neuroglia-cells are also represented.

Neuroglia-fibres are contained within prolongations or cell-processes of branching neuroglia-cells (*glia-cells*). These cells are stellate in shape (fig. 244), and their fine processes pass as neuroglia-fibres between the nerve-cells and nerve-fibres, which they aid in supporting (fig. 243). There appear to be two kinds of these neuroglia-cells differing from one another in the character of their processes (Andriezen). In the one kind the processes branch repeatedly (*arborescent cells*); in the other kind they remain un

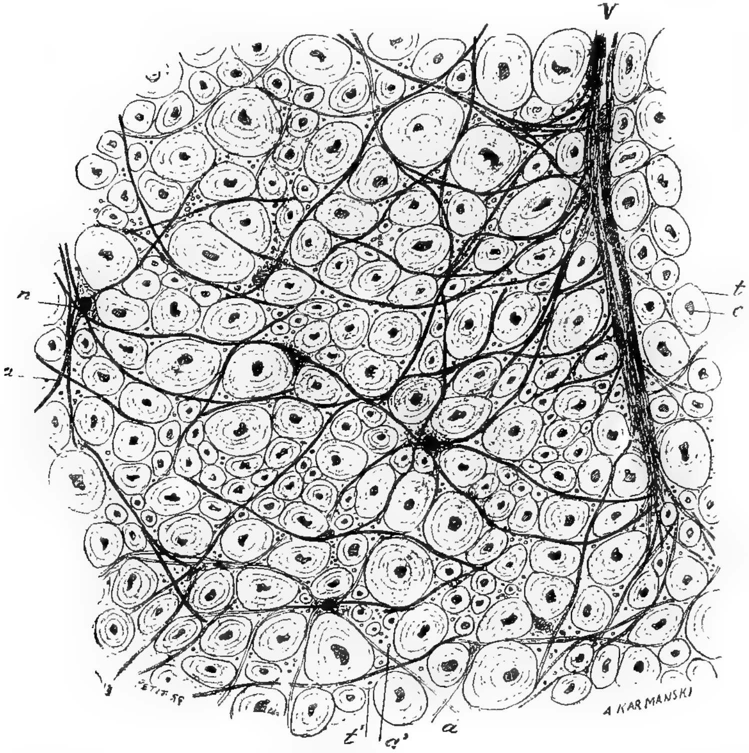

FIG. 243.—TRANSVERSE SECTION OF WHITE MATTER OF SPINAL CORD, SHOWING NERVE-FIBRES CUT ACROSS AND NEUROGLIA-FIBRES AMONGST THEM. (Ranvier.)

t, a medullary nerve-fibre; *c*, its axis-cylinder; *t'*, a small fibre; *n*, neuroglia cell-body; *a*, *a*, neuroglia-fibres; *a'* others cut across.

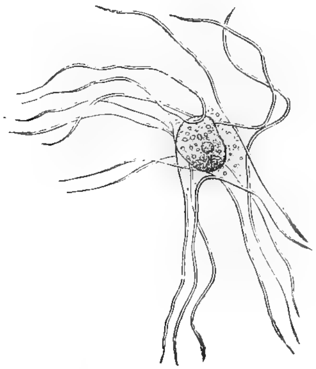

FIG. 244.—NEUROGLIA-CELL FROM SPINAL CORD. (Ranvier.)

Isolated after maceration in 33 per cent. alcohol.

branched from their origin in the cell-body to their termination (*spider-cells*) (fig. 245, A and B).

DEVELOPMENT OF NERVE-CELLS AND NERVE-FIBRES.

All nerve-cells in the body are developed from the cells of the neural groove and neural crest of the early embryo; the neural groove closing to form the neural canal (fig. 246), the cells of which form the spinal cord and brain, and the neural crest giving off at intervals sprouts which become the germs of the spinal ganglia. The cells which line the neural canal are at first all long columnar cells, but amongst these, and probably produced by cell-division from some of them (fig. 247, *g*; fig. 250, A), rounded cells,

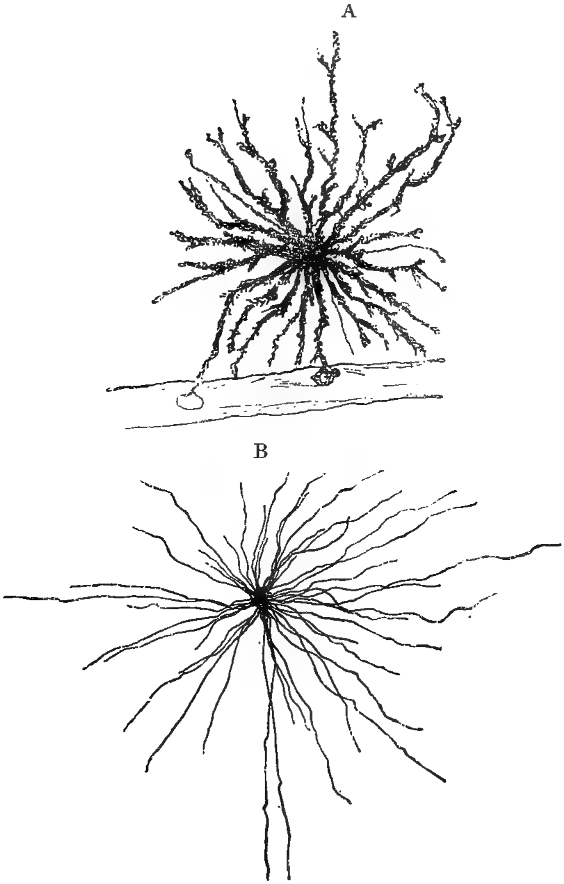

FIG. 245.—NEUROGLIA-CELLS. GOLGI METHOD. (Andriezen.)

A, a dendritic cell, showing two of its processes attached to the wall of a vessel.
B, a spider cell with long interlacing but unbranched processes.

neuroblasts, make their appearance, the remaining elongated cells forming the *spongioblasts*. Soon from each neuroblast a process begins to grow out

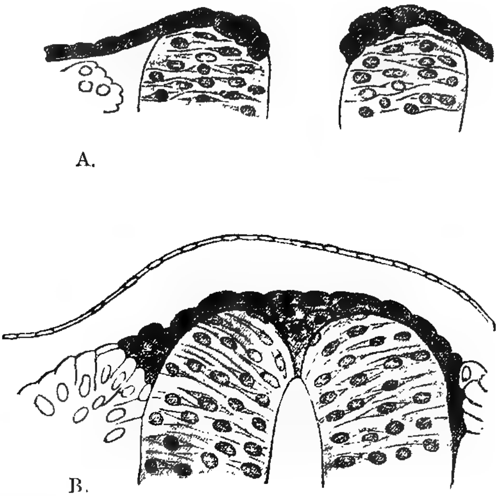

Fig. 246.—Closure of neural canal of human embryo, showing the cells of the neural crest becoming segregated to form the germs of the spinal ganglia. (v. Lenhossék.)

A, canal still open; *B*, canal closed.

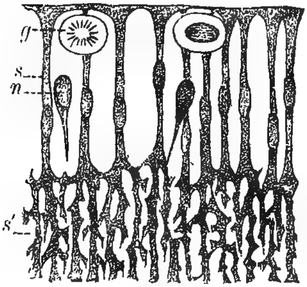

Fig. 247.

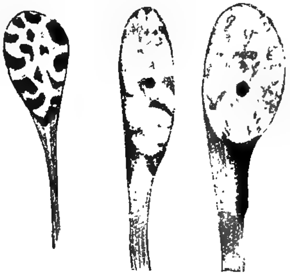

Fig. 248.

Fig. 247.—Section of neural epithelium of early embryo. (His.)

Highly magnified view of part of a section, at the time of the first differentiation of the neuroblasts, showing *s*′, spongework formed of the outer ends of columnar epithelium cells, *s*; *g*, rounded "germinal cells" in process of division (probably to form neuroblasts); *n*, a neuroblast.

Fig. 248.—Neuroblasts from a pig embryo, showing three stages of development. (Gurwitsch, after Scott.) Highly magnified.

(fig. 247, *n*; fig. 248; fig. 250). This is the axon, and it is usually characterised by an enlarged extremity (*incremental cone*) (fig. 249, *b*, *c*, *d*, *h*, *i*; fig. 250, *d*, *e*). Some of these growing axons emerge from the ventro-lateral region of the canal and become the *axis-cylinders* of *motor nerves*. The

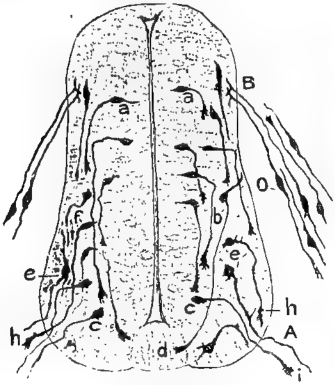

FIG. 249.

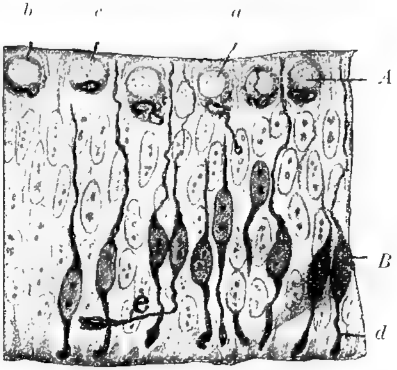

FIG. 250.

FIG. 249. SECTION OF SPINAL CORD OF CHICK OF THIRD DAY OF INCUBATION. (Cajal.)

A, ventral root-fibres formed by outgrowths of motor neuroblasts, *e*, *e*; *B*, dorsal root-fibres formed by ingrowths of bipolar sensory neuroblasts, *o*, in ganglion rudiment; *a*, early neuroblasts; *b*, neuroblast giving rise to a commissural nerve-fibre, *d*; *h*, *i*, enlarged ends of growing axons; *e*, *e*, neuroblasts of which the dendrons are beginning to appear.

FIG. 250.—SECTION OF PART OF NEURAL CANAL OF CHICK OF TWO AND A HALF DAYS. (Cajal.)

A, germinal layer containing spherical neuroblasts, *a*, *b*, *c* (of these a neuro-fibril has already begun to grow out from *a*); *B*, neuroblasts in a bipolar stage; *d*, enlarged end of growing axon; *e*, another growing tangentially.

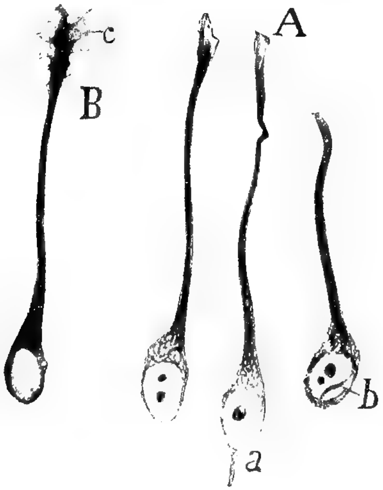

FIG. 251.—NEUROBLASTS FROM THE SPINAL CORD OF A THIRD-DAY CHICK EMBRYO. (Cajal.)

A, three neuroblasts, stained by Cajal's reduced silver method, showing a network of neuro-fibrils in the cell-body; *a*, a bipolar cell. *B*, a neuroblast stained by the method of Golgi, showing the incremental cone, *c*.

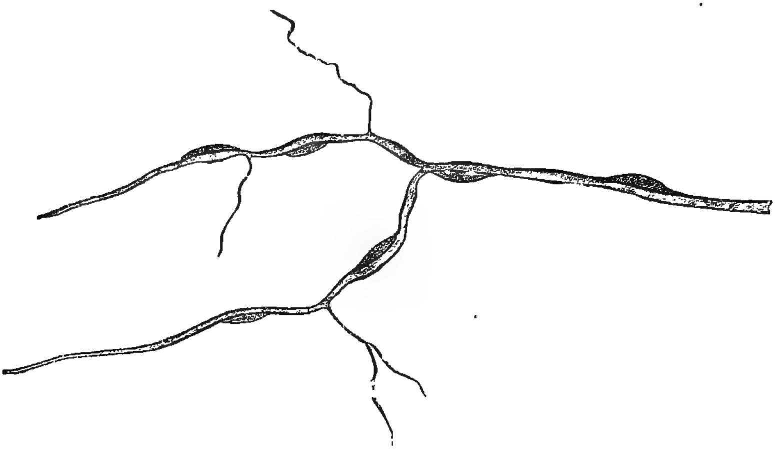

FIG. 252.—GROWING NERVE-FIBRES IN TAIL OF TADPOLE. (Kölliked.)

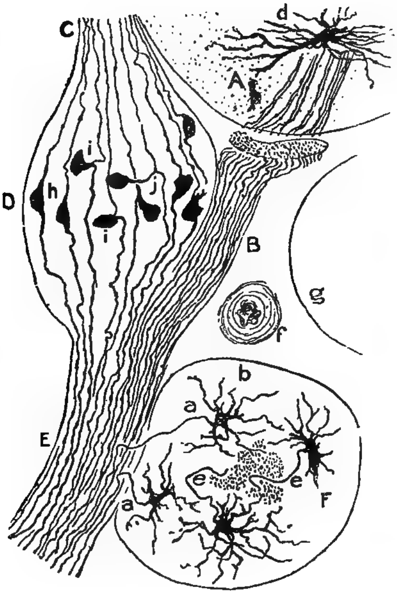

FIG. 253.—SPINAL AND SYMPATHETIC GANGLIA AND PART OF SPINAL CORD OF CHICK OF SEVENTEENTH DAY OF INCUBATION. (Cajal.)

A, ventro-lateral part of spinal cord with *d*, a motor nerve-cell; the fibres of the ventral root are seen emerging and passing to *B* (the connexion appears interrupted in the section); *C*, posterior root formed of fibres which have grown from the ganglion-cells in *D*, spinal ganglion; *E*, mixed spinal nerve; *F*, sympathetic ganglion; *a*, *a*, axons of sympathetic cells, passing to join the spinal nerve; *b*, dendrons of these cells; *e*, axons passing to the sympathetic cord; *h*, cells of spinal ganglion still bipolar; *i*, *i*, bipolar cells becoming transformed into unipolar; *j*, unipolar cell with T-junction; *f*, section of an artery; *g*, body of vertebra.

dendrons of the cells appear somewhat later than the axons. The axis-cylinder processes of some of the neuroblasts remain within the nerve-centre ; from these are developed the commissural, association, and intercentral fibres. Harrison has directly observed the outgrowth of the axon processes of the neuroblasts of the amphibian larva in isolated neuroblasts examined in serum under the microscope. The growth of nerve-fibres can also be observed at the ends of the developing nerve-fibres in the tail of the tadpole (fig. 252).

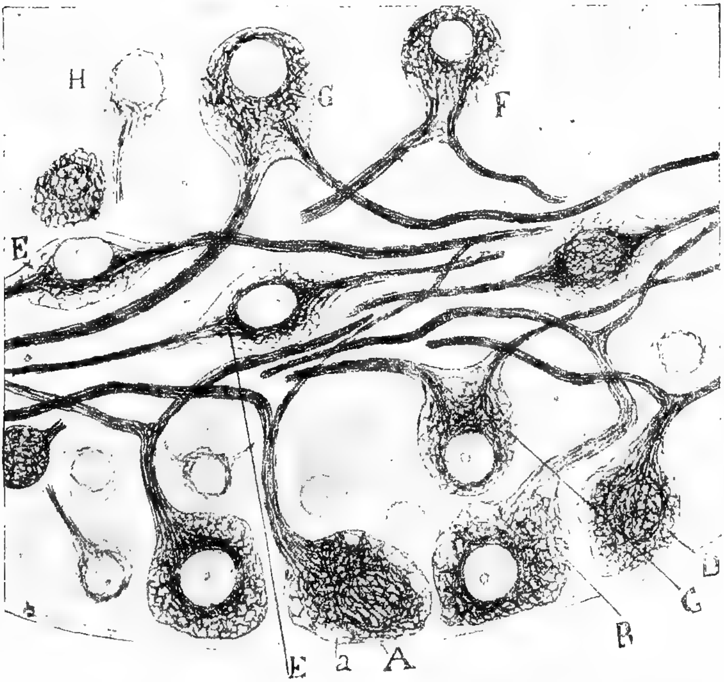

Fig. 254.—Spinal ganglion-cells of embryo at period of transition from bipolar to unipolar cells. (Cajal.)

The preparation has been stained to show the neuro-fibrils. *A*, *B*, unipolar cells ; *C*, *D*, *F*, *G*, transitional forms ; *E*, *E*, bipolar cells ; *H*, small cell with neuro-fibrils incompletely developed.

The sprouts from the neural crest contain the neuroblasts from which the dorsal root-fibres are developed. Axons grow out from these neuroblasts in two directions, so that the cells become bipolar (figs. 249, 253). One set of processes, forming the dorsal root-fibres, grows into the dorsal portion of the neural canal and its fibres ramify in the developing grey matter ; the other set, containing the afferent fibres of the spinal nerves, remains outside the canal and grows towards the developing ventral roots, eventually mingling with them to form the mixed nerves. As development proceeds, the bipolar ganglion cells become gradually transformed in most vertebrates, by a shifting of the two axons, into unipolar cells (fig. 253, *h*, *i*, *j*; fig. 254); but in some fishes the cells remain permanently bipolar (fig. 220). This is also the case with the ganglion-cells of the eighth cranial nerve (ganglion of Scarpa and ganglion of the cochlea).

The ganglia on the sympathetic and on other peripheral nerves are developed from small masses of neuroblast cells which have wandered along the course of the out-growing nerve-fibres, and give origin to axons and dendrons much in the same way as do the neuroblasts within the central nervous system.

The manner in which the medullary sheath and neurolemma of the nerve-fibres are formed is not fully understood. It is probable that the medullary substance at any rate is formed by the axis-cylinder itself, whilst the neurolemma with its nuclei is derived from cells (*lemmal cells*) which have wandered out from the neural ectoderm along with the outgrowths from the neuroblasts and accompany them in their progress to the tissues. It is however possible that the lemmal cells are of mesodermic origin.

Certain neurologists are of opinion that the nerve-fibres do not grow out from single nerve-cells in the manner above described, but are formed of chains of cells which emerge from the neural ectoderm or from the ganglion-rudiments, and join end to end into a syncytium, which gradually lengthens out into the nerve-fibre, the nuclei of the syncytium becoming the nuclei of the neurolemma, and the protoplasm of the syncytium becoming differentiated into axis-cylinder, medullary sheath, and neurolemma as development advances.

Development of neuroglia.—The neuroglia is developed from the spongioblasts of the neural canal. These, in place of giving off an axon and dendrons like the neuroblasts, send out a number of fine processes in all directions from the cell-body to form the fibres of the neuroglia. It is held by some authorities that the neuroglia has a double origin, some of the cells—those with unbranched processes—being developed from ectoderm and the others from mesoderm.

LESSON XIX.

MODES OF TERMINATION OF NERVE-FIBRES.

1. Shell out a Pacinian corpuscle from a piece of cat's mesentery, which may either be fresh or may have been kept for two or three days in $\frac{1}{20}$ per cent. chromic acid or in 5 per cent. formol. Clear it as much as possible of adhering fat, but be careful not to prick or otherwise injure the corpuscle itself. Mount in water or saline with a thick hair to prevent crushing with the cover-glass. Sketch the corpuscle under a low power, and afterwards draw under a high power the part of the core where the nerve enters and the part where it terminates. Notice the fibrous structure of the lamellar tunics of the corpuscle and the oval nuclei belonging to flattened epithelioid cells which cover the tunics. The distinct lines, which when seen in the fresh corpuscles are generally taken for the tunics, are really the optical sections of these flattened cells.

2. Pacinian corpuscles may also be observed in sections of the skin (in the subcutaneous tissue). Tactile corpuscles may be seen in the papillæ of the palmar surface of the hand and fingers. Their study may be reserved until the skin is dealt with.

3. Dissect off a small portion of conjunctiva from the eye of a calf or other animal which has been quite freshly killed. Spread it out on a slide with the under surface uppermost, and place upon it a drop of 1 per 1000 methylene blue solution. Watch the preparation with a low power until the nerve-fibres come into view, then cover and trace them with the high power. They will be seen to end in elongated end-bulbs.

Somewhat similar endings can be shown in the same manner in a piece of parietal peritoneum stripped off and laid out flat upon a slide and mounted in methylene blue solution.

4. Study the corpuscles of Grandry and of Herbst in sections of the skin covering the duck's bill.

5. Mount in dilute glycerine sections of a rabbit's cornea which has been stained with chloride of gold by Klein's method (see Appendix). Notice the arrangement in plexuses of the darkly-stained nerve-fibres and fibrils, (1) in the connective-tissue substance, (2) under the epithelium, and (3) between the epithelial cells. Make one or two sketches showing the arrangement of the fibrils.

6. Spread out a small piece of muscle which has been stained with chloride of gold by Löwit's method, or with methylene blue by Ehrlich's method, and examine it with a low power to find the nerve-fibres crossing the muscular fibres and distributed to them. Occasionally the nerve-fibres which end in the muscle-spindles may be observed.

The pieces of muscle are advantageously thinned out for observation by pressure upon the cover-glass. Search thoroughly for the close terminal ramifications (end plates) of the axis-cylinders immediately within the sarcolemma. The motor endings are most readily shown in the muscles of reptiles such as snakes and lizards.

These nerve-endings as well as others elsewhere can also be displayed in preparations made by other methods (see Appendix).

Modes of ending of sensory nerve-fibres.—Nerve-fibres which are distributed to sensory parts end either in *special organs* or in free *terminal* *ramifications*, these last being usually in epithelia. Within the special organs the actual nerve-ending is also generally ramified.

Nerve-endings in special connective-tissue organs.—Three chief kinds of these special organs are usually described, represented in man by *Pacinian corpuscles*, *tactile corpuscles*, and *end-bulbs*. The type is the same in all: a lamellated connective-tissue *capsule* enclosing a *core* of a soft material which appears to be mainly composed of nucleated protoplasmic cells with fibres between them. The capsule is an expansion of the perineurium, and the core an expansion of the endoneurium of the nerve. Within the core the axis-cylinder terminates either simply or by an arborescence. The variations which occur are chiefly due to the complexity of this arborescence and that of the capsule, which is simplest in the end-bulbs and most complex in the Pacinian corpuscles. In the **tactile corpuscles** and **end-bulbs** the connective-tissue sheath of the medullated fibre expands to form a bulbous enlargement, which is cylindrical or spheroidal in end-bulbs and ellipsoidal in tactile corpuscles. In both kinds of end-organ as the nerve-fibre enters (which in the tactile corpuscle only happens when it has reached the distal part, after having wound spirally once or twice round the corpuscle) it loses

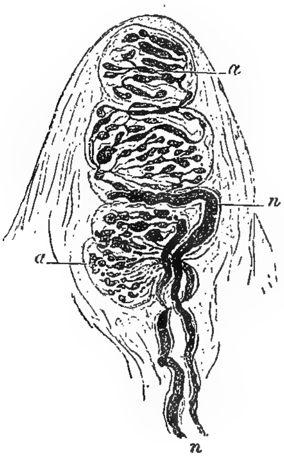

Fig. 255.

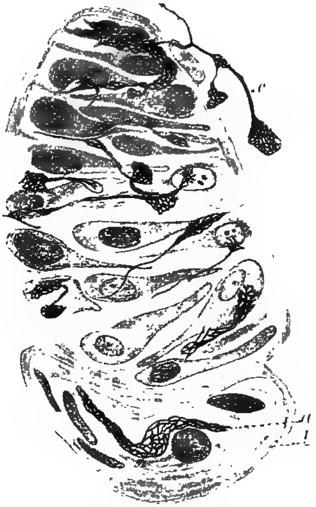

Fig. 256.

Fig. 255.—Tactile corpuscle within a papilla of the skin of the hand, stained with chloride of gold. (Ranvier.)

n, two nerve-fibres passing to the corpuscle; *a*, *a*, varicose ramifications of the axis-cylinders within the corpuscle.

Fig. 256.—Section of a tactile corpuscle, showing the cells composing the core and the ramifications of the axis-cylinder amongst them, ending in fibrillated enlargements. (Van de Velde.)

a, axis-cylinder; *b*, capsule of corpuscle; *c*, a nerve-termination outside the corpuscle.

its sheath and is prolonged as an axis-cylinder only. This generally soon ramifies and its branches terminate after either a straight or a convoluted course within the organ; but it sometimes remains almost unbranched (see figs. 225 to 260).

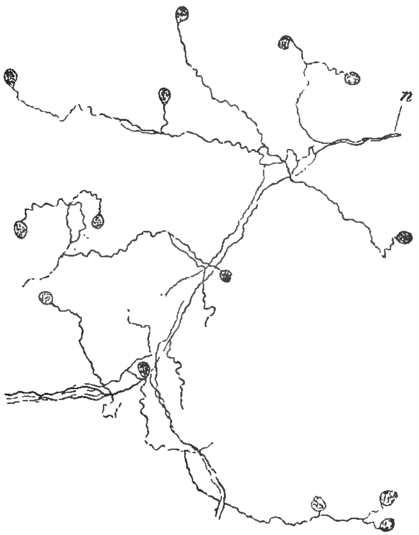

FIG. 257.—END-BULBS AT THE TERMINATIONS OF NERVES IN THE HUMAN CONJUNCTIVA, AS SEEN WITH A LENS. (Longworth.)

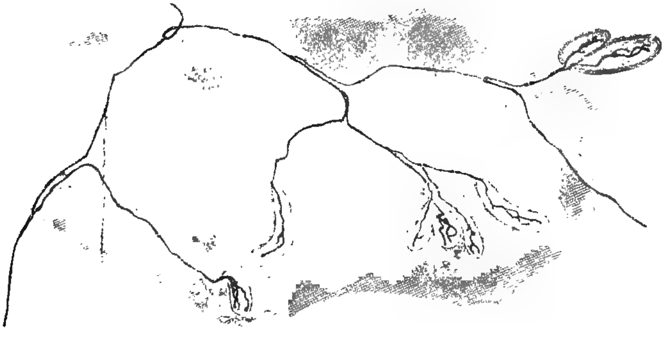

FIG. 258.—A MEDULLATED FIBRE TERMINATING IN SEVERAL END-BULBS IN THE HUMAN PERITONEUM. (A. S. Dogiel.) Methylene blue preparation. Low power.

Tactile corpuscles occur in some of the papillæ of the skin of the hand and foot, in sections of which they will be studied (see fig. 367, p. 264). End-bulbs are

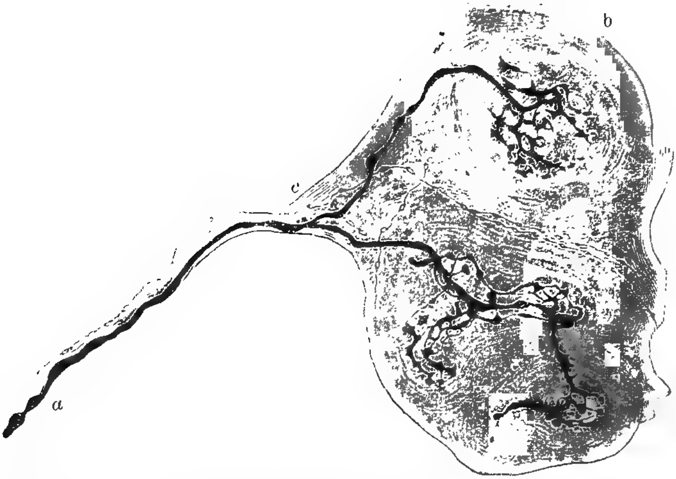

FIG. 259.—END-BULBS FROM THE HUMAN PERITONEUM. (Dogiel.) More highly magnified. Methylene blue preparation.

a, medullated fibre; *b*, nucleated lamellated capsule of end-bulb; *c*, non-medullated fibres, probably destined for the capillaries which surround the end-bulbs.

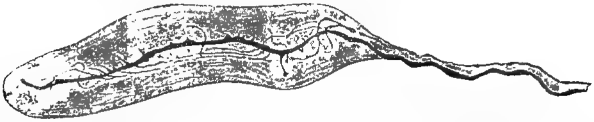

FIG. 260.—END-BULB FROM THE CENTRAL TENDON OF THE DIAPHRAGM OF THE DOG. (Dogiel.) Showing besides the main medullated fibre terminating by an arborescence within the core, a second very fine medullated fibre, forming a more delicate arborescence around the ending of the main fibre in the outer part of the core. Methylene blue preparation.

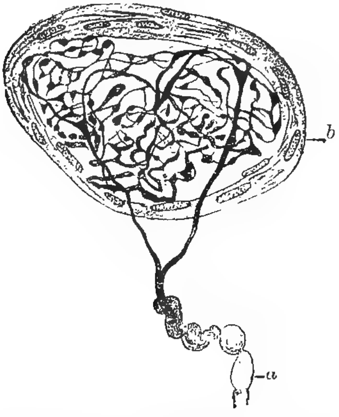

FIG. 261.—END-BULB FROM THE GLANS PENIS, SHOWING TERMINATION OF AXIS-CYLINDER. Methylene blue preparation. (Dogiel.)

a, medullated nerve-fibre; *b*, sheath of end-bulb.

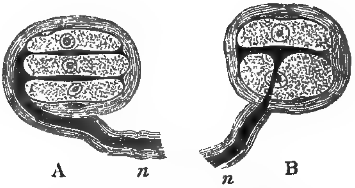

FIG. 262.—GRANDRY CORPUSCLES FROM THE DUCK'S TONGUE. (Izquierdo.)

A, composed of three cells, with two interposed disks, into which the axis-cylinder of the nerve, *n*, is observed to pass; in *B* there is but one tactile disk enclosed between two tactile cells.

found in the conjunctiva of the eye, where in most animals they have a cylindrical or oblong shape, but in man they are spheroidal (fig. 257). They have also been found in papillæ of the lips and tongue, in serous membranes, in tendons and aponeuroses, and in the epineurium of the nerve-trunks; and somewhat similar sensory end-organs (*genital corpuscles*) also occur in the integument of the external genital organs of both sexes (fig. 261). Similar bodies of larger size are also met with in the neighbourhood of the joints (*articular corpuscles*). In the skin

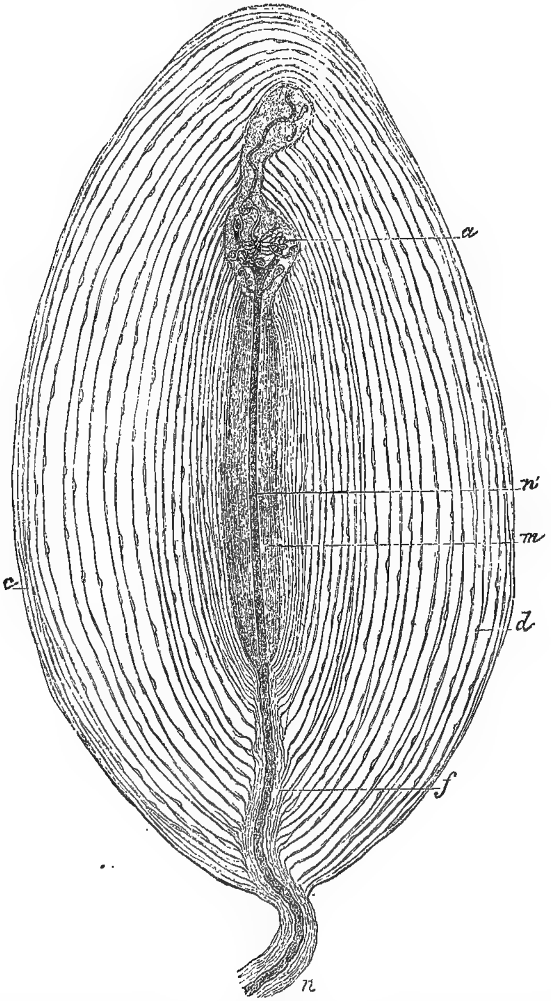

FIG. 263.—MAGNIFIED VIEW OF A PACINIAN BODY FROM THE CAT'S MESENTERY. (Ranvier.)

n, stalk of corpuscle with nerve-fibre, enclosed in sheath of Henle, passing to the corpuscle; *n*, its continuation through the core, *m*, as axis-cylinder only; *a*, its terminal arborisation; *c*, *d*, sections of epithelioid cells of tunics, often mistaken for the tunics themselves; *f*, channel through the tunics which expands into the core of the corpuscle.

covering the bills of certain birds (*e.g.* duck), a simple form of end-organ (*corpuscle of Grandry*, fig. 262) occurs, consisting of two or more cells arranged in rows within a capsule, with the axis-cylinder terminating in flattened expansions (*tactile disks*) between the cells.

The **Pacinian corpuscles** (figs. 263, 264) are larger and have a more complex structure than the tactile corpuscles and end-bulbs. They are composed of a number of concentric coats arranged like the layers of an onion, and enclosing the prolonged end of a nerve-fibre. A single medullated nerve-fibre goes to each Pacinian corpuscle, encircled by a prolongation of the perineurium (*sheath of Henle*), and within this by endoneurium; when it reaches the corpuscle, of which it appears to form the stalk, the lamellæ of the perineurium expand into the tunics of the capsule. The nerve passes on, piercing the tunics, surrounded by endoneurium, and still provided with medullary sheath, to reach the central part of the corpuscle. Here the endoneurium is prolonged to form a core of cylindrical shape, along the middle of which the nerve-fibre, now deprived of its medullary sheath and neurolemma, passes in a straight course as a simple axis-cylinder (figs. 263, *n′*; 265, *c.f*) to terminate at the farther end of the core, either in an arborisation or in a bulbous enlargement. In its course through the core it may give off lateral ramifications, which penetrate to all parts of the core, and themselves end in fine branches.

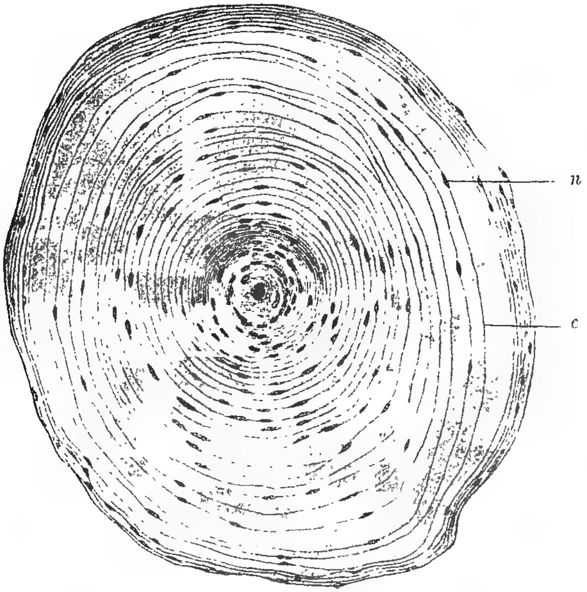

FIG. 264.—SECTION OF PACINIAN CORPUSCLE. (Szymonowicz.)

c, one of the layers of epithelioid cells; *n*, nucleus of epithelioid cell. It is seen that the tunics are very closely packed around the core, in the middle of which the axial-fibre is cut across.

Besides the medullated fibre, which is always very conspicuous, it has been shown that both the Pacinian and Herbst corpuscles (see below) receive a fine non-medullated nerve-fibre which arborises over the outer surface of the core. A similar arrangement also obtains in Grandry's corpuscles, where the tactile cells are surrounded with such an arborisation (Dogiel and others).

The tunics of the capsules are composed of connective tissue, the fibres of which for the most part run circularly. They are covered on both surfaces with a layer of flattened epithelioid cells (fig. 266), and here and there cleft-like lymph-spaces can be seen between them like those between the layers of the perineurium.

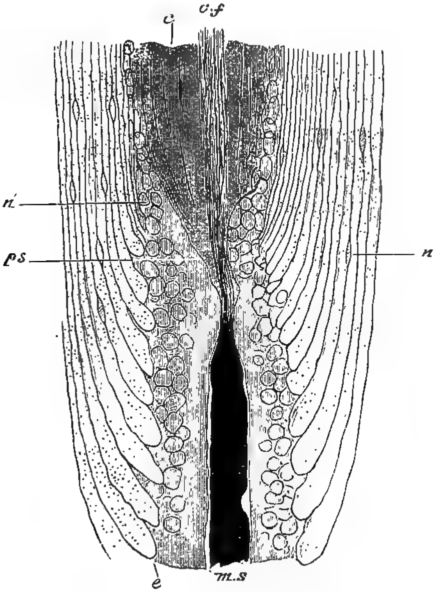

FIG. 265.

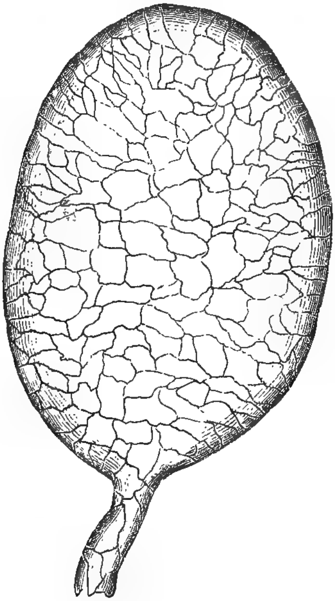

FIG. 266.

FIG. 265.—PART OF PACINIAN BODY, SHOWING THE NERVE-FIBRE ENTERING THE CORE. FROM AN OSMIC ACID PREPARATION.

ms, entering nerve-fibre, the medullary sheath of which is stained darkly, and ends abruptly at the core, *c*; *ps*, prolongation of primitive sheath or neurolemma passing towards the outer part of the core; *c.f*, axis-cylinder passing through the core as the central fibre; *e*, some of the inner tunics of the corpuscle, enlarged where they abut against the canal through which the nerve-fibre passes—the dots within them are sections of the fibres of which they are composed; *n*, nuclei of the tunics; *n'*, nuclei of the endoneurium-cells, continued by others in the outer part of the core.

FIG. 266.—PACINIAN CORPUSCLE FROM THE CAT, STAINED WITH SILVER NITRATE. (Drawn by G. C. Henderson.)

A simple form of Pacinian corpuscle with fewer tunics and a core formed of regularly arranged cells occurs in birds (*corpuscles of Herbst*, fig. 267).

Pacinian corpuscles occur in many situations, especially in the deeper layers of the skin of the hands and feet, in the periosteum of some bones, in the neighbourhood of tendons and ligaments, in the connective tissue at the back of the abdomen and (in the cat) very numerously in the mesentery, where they are most easily got for observation.

Although most of the nerve-endings in connective-tissue structures are enclosed within lamellated capsules, nerves are found to end in some situations in arborisations between bundles of connective-tissue fibres. This has been shown by Dogiel to occur in intermuscular connective-tissue septa (fig. 268); and in serous membranes (fig. 269); in the latter such arborisations may be quite superficial and placed just below the endothelium.

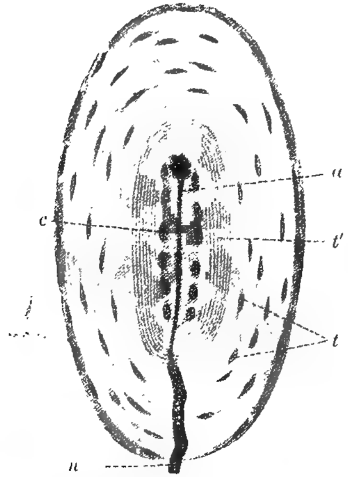

Fig. 267.—Herbst corpuscle of duck. (Sobotta.) × 380.

n, medullated nerve-fibre; *a*, its axis-cylinder, terminating in an enlargement at end of core; *c*, nuclei of cells of core; *t*, nuclei of cells of outer tunics; *t'*, inner tunics.

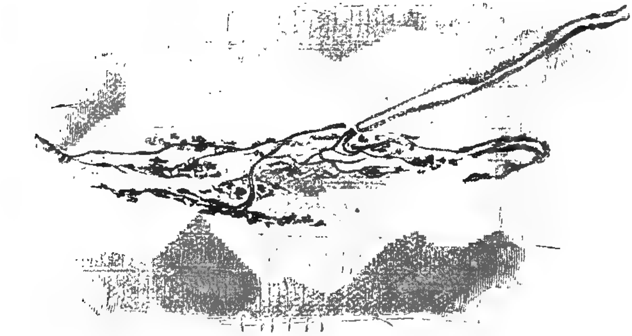

Fig. 268.—Terminal arborisation from the intermuscular connective tissue of the rectus abdominis of the rabbit. Methylene blue preparation. (Dogiel.)

Organs of Ruffini.—These, which resemble long cylindrical end-bulbs, are connective-tissue bundles, within which the axis-cylinders of the nerves ramify, ending in flattened expansions (fig. 270). They occur fairly numerously in the subcutaneous tissues of the finger. Other end-bulb-like organs, spheroidal, oval, or cylindrical in form, have been described by Ruffini

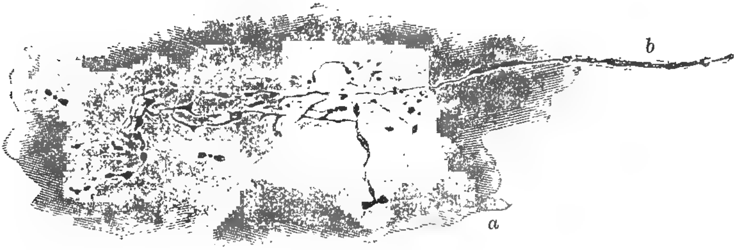

FIG. 269.—TERMINAL ARBORISATION FROM THE SUPERFICIAL LAYER OF THE PERITONEUM OF THE RABBIT. METHYLENE BLUE PREPARATION. (Dogiel.)

a, medullated fibre; *b*, fibre connecting the arborisation with another one not here represented.

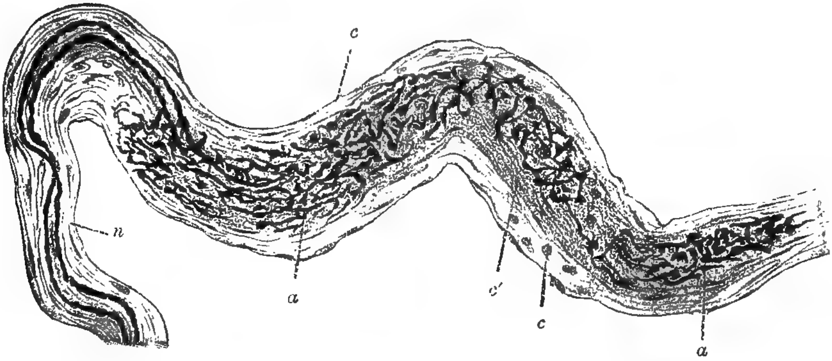

FIG. 270.—AN ORGAN OF RUFFINI FROM THE SUBCUTANEOUS TISSUE. (Ruffini.)

n, entering nerve-fibres; *a*, *a*, ending of their axons; *c*, *c*, capsule of organ; *c'*, core.

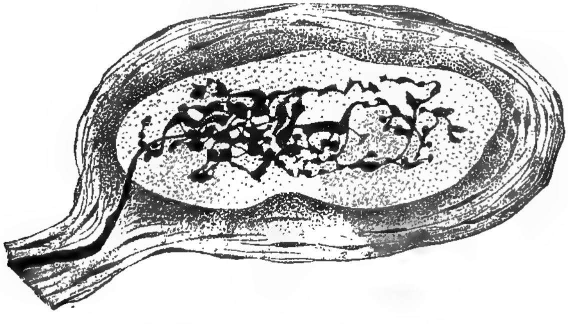

FIG. 271.—ORGAN OF GOLGI-MAZZONI FROM SUBCUTANEOUS TISSUE. (Ruffini.)

The organ resembles an end-bulb in general structure.

under the name of Golgi-Mazzoni corpuscles (fig 271); they appear to be varieties of the end-bulb. They also occur in the subcutaneous tissue of the pulp of the finger and in tendons.

Organs of Golgi.—A special mode of nerve-ending is met with in many tendons, near the points of attachment of the muscular fibres. The tendon-bundles become somewhat enlarged and split into a number of smaller fasciculi, and the nerve-fibres—one, two, or even more in number—pass to the enlarged part, and penetrating between the fasciculi of the tendon lose their medullary sheaths, while the axis-cylinders end in a terminal arborisation, beset with irregular varicosities. The structure (figs. 272, 273) is enclosed within a fibrous capsule continuous with the areolar tissue covering the bundles of the tendon; and between the capsule and the organ proper

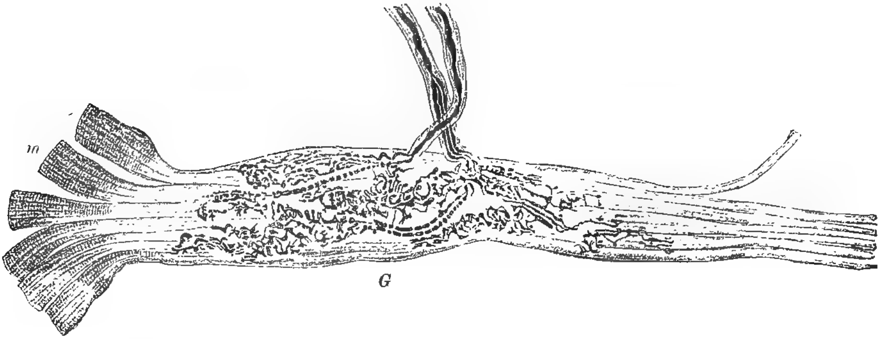

FIG. 272.—ORGAN OF GOLGI FROM THE HUMAN TENDO ACHILLIS. CHLORIDE OF GOLD PREPARATION. (Ciaccio.)
m, muscular fibres; *t*, tendon-bundles; *G*, Golgi's organ; *n*, two nerve-fibres passing to it.

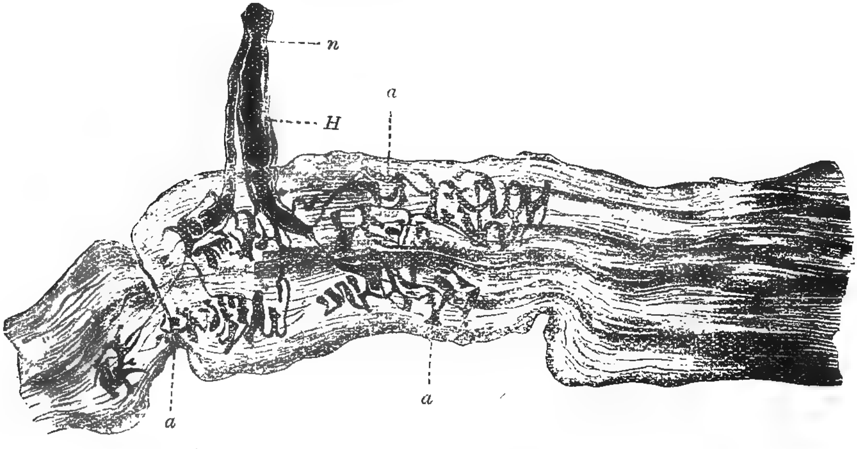

FIG. 273.—ORGAN OF GOLGI; MORE HIGHLY MAGNIFIED. (Ciaccio.)
n, entering nerve-fibre; *H*, its sheath of Henle; *a*, *a*, ramification of axis-cylinders between the tendon-bundles.

is a lymph-space, similar to that which is found in the muscle-spindle (see p. 200).

Free nerve-endings.—When sensory nerve-fibres terminate in epithelium, they generally branch once or twice in the subepithelial connective tissue on nearing their termination. The sheaths of the fibres then successively become lost, first the connective tissue or perineural sheath, then the medullary sheath, and lastly the neurolemma, the axis-cylinder being alone continued as a bundle of neuro-fibrils. This branches, and interlacing with the ramifications of the axis-cylinders of neighbouring nerve-fibres forms a primary plexus. From the primary plexus smaller branches come off, and form a secondary plexus nearer the surface, generally immediately under the epithelium if the ending is in a membrane covered by that tissue. Finally, from the secondary plexus nerve-fibres proceed and terminate by ramifying amongst the tissue cells (fig. 274, *p*, *b*), the actual ending being generally in free varicose fibrils (*b*). This mode of

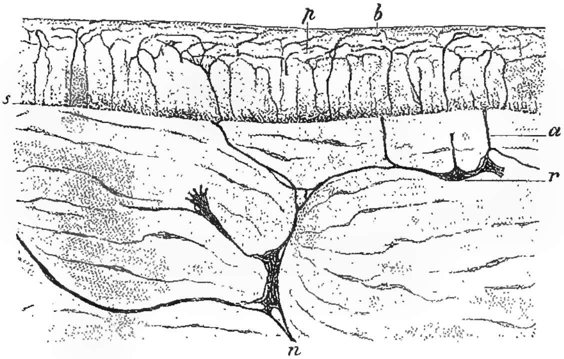

FIG. 274.—VERTICAL SECTION OF CORNEA STAINED WITH CHLORIDE OF GOLD. (Ranvier.)

n, *r*, primary plexus in connective tissue of cornea ; *a*, branch passing to subepithelial plexus, *s* ; *p*, intra-epithelial plexus ; *b*, terminations of fibrils.

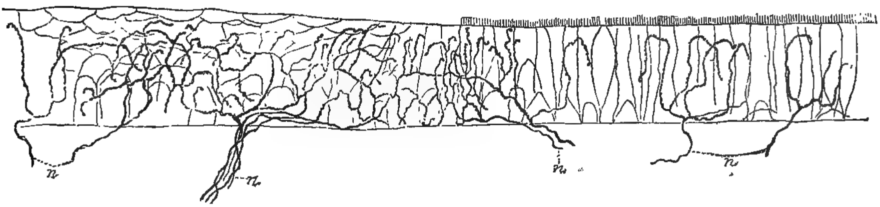

FIG. 275.—INTRA-EPITHELIAL NERVE-TERMINATIONS IN THE LARYNX. GOLGI METHOD. (G. Retzius.)

On the left the epithelium is stratified and on the right ciliated columnar. *n*, nerve-fibres in corium.

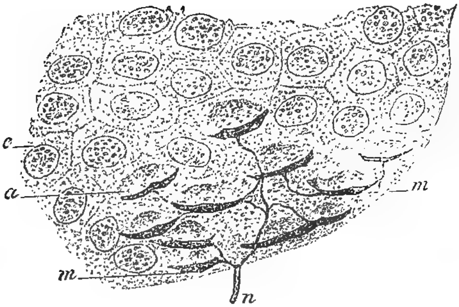

Fig. 276.

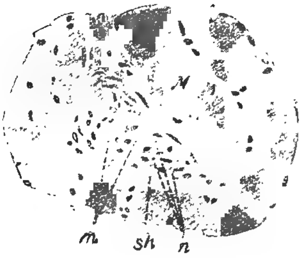

Fig. 277.

Fig. 276.—Ending of nerve in tactile disks in the pig's snout. (Ranvier.)

n, medullated fibre; **m**, terminal disks or menisci; **e**, cells of the Malpighian layer of the epidermis; **a**, somewhat modified cell to which a tactile disk is applied.

Fig. 277.—Section of muscle-spindle. (Sobotta.) Magnified 40 diameters.

sh, sheath of spindle; *m*, intrafusal muscle-fibres; *n*, nerve-fibres; *M*, ordinary muscle-fibres.

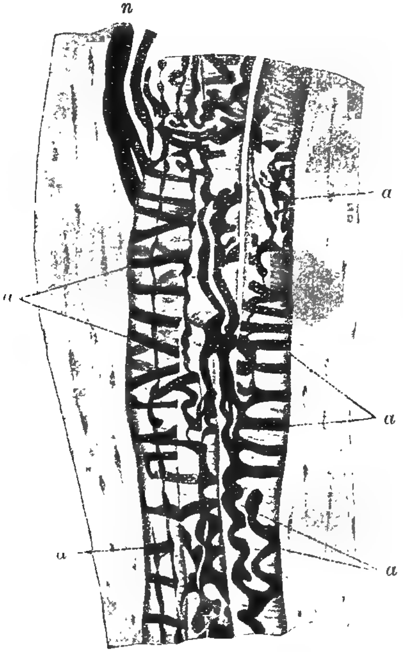

Fig. 278.—Ending of nerve-fibres in muscle-spindle. (Ruffini.)

Three intrafusal muscle-fibres are shown. *n*, nerve-fibres entering spindle; *a*, axis-cylinders terminating around and between the intrafusal fibres in ring-like, spiral, and irregularly ramified endings.

ending is characteristically seen in the cornea of the eye, but can also be rendered evident in other epithelia (fig. 275).

In some situations the nerve-fibrils within a stratified epithelium terminate in flattened or crescentic expansions which lie in the interstices of

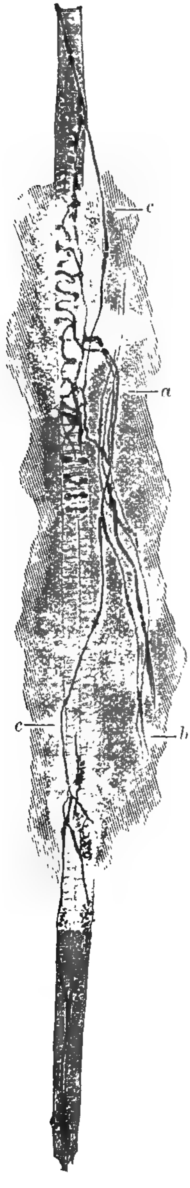

FIG. 279.

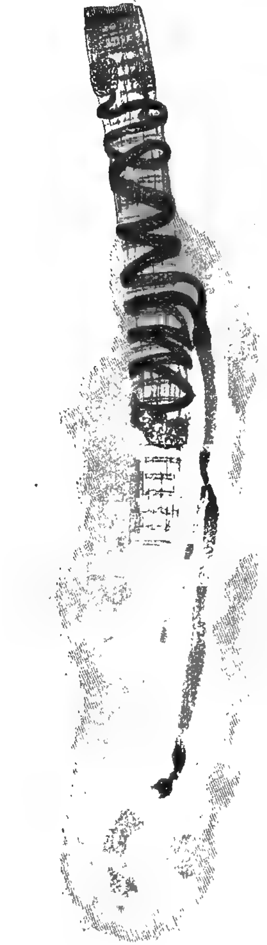

FIG. 280.

FIG. 279.—NERVE-ENDINGS UPON THE INTRAFUSAL MUSCLE-FIBRES OF A MUSCLE-SPINDLE OF THE RABBIT; MODERATELY MAGNIFIED. METHYLENE BLUE PREPARATION. (Dogiel.)

a, large medullated fibre coming off from "spindle" nerve and passing to end in an annulo-spiral termination on and between the intrafusal fibres; *b*, a fine medullated fibre coming off from the same stem and dividing. Its branches, *c*, pass towards the ends of the muscle-fibres and terminate in a number of small localised arborisations.

FIG. 280.—AN ANNULO-SPIRAL ENDING OF INTRAFUSAL FIBRE; HIGHLY MAGNIFIED. METHYLENE BLUE PREPARATION. (Dogiel.)

the deeper epithelium cells, to some of which they are applied. These expansions are known as *tactile disks*; they are characteristically developed in the skin of the pig's snout (fig. 276), and are also found in the outer root sheath of hairs and in the deeper parts of the epidermis in various parts. With appropriate treatment it may be shown that they consist of a fine network of neuro-fibrils.

Sensory nerves of muscles.—The sensory nerves of muscles end in peculiar organs which were termed by Kühne *muscle-spindles.* Their structure has recently been specially investigated by Ruffini, Huber, and Dogiel, and also by Sherrington, who has shown that the large medullated nerves which they receive (about three or four such fibres entering each spindle not far from its equator) are derived from the dorsal root-ganglia.

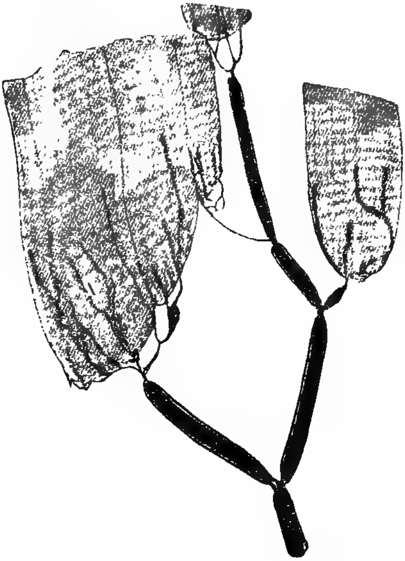

Fig. 281.—Sensory nerve terminating in arborisations around the ends of muscle-fibres. (Ceccherelli.)

The **muscle-spindle** is a fusiform body, from 0·75 to 4 mm. long, and from 0·08 to 0·2 mm. in diameter; it lies parallel with the general direction of the fibres of a muscle. It consists of a lamellated connective-tissue sheath externally, within which is a bundle (intrafusal bundle) of from two to twelve peculiar muscle-fibres (fig. 277). These with some connective tissue and the nerve-fibres form an axial mass; between this axial bundle and the sheath is a lymphatic periaxial space, bridged across by filaments of connective tissue. The intrafusal muscle-fibres are somewhat like embryonic fibres in appearance, being smaller than the ordinary fibres of the muscle and having a relatively large number of nuclei with surrounding protoplasm, as in the red variety of muscle. At the proximal end of the spindle they are usually only two or three in number, but they become cleft as they pass through it; at the distal end they may terminate in tendon-bundles. The nerve-fibres which pass to the spindle are mostly of large size; they divide after reaching the intrafusal bundle, but retain their medullary sheath for a time, although eventually terminating as axis-cylinders, which wind in a spiral manner between

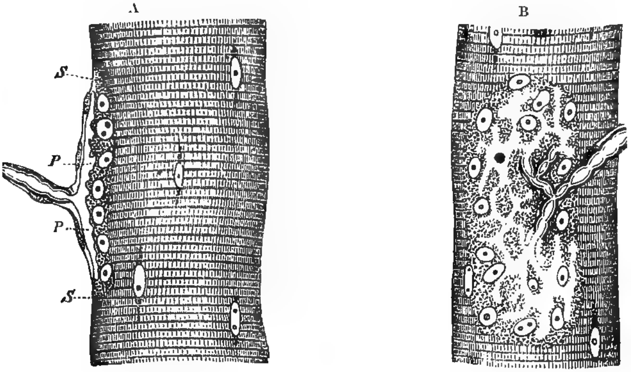

FIG. 282.—NERVE-ENDING IN MUSCULAR FIBRE OF A LIZARD (*Lacerta viridis*). (Kühne.)

A, end-plate seen edgeways; *B*, from the surface; *s*, *s*, sarcolemma; *p*, *p*, expansion of axis-cylinder. In *B* the expansion of the axis-cylinder appears as a clear network branching from the divisions of the medullated fibres.

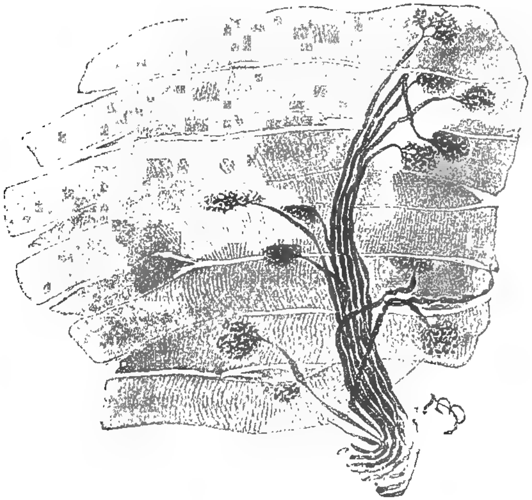

FIG. 283.—MOTOR NERVE-ENDINGS IN THE ABDOMINAL MUSCLES OF A RAT. GOLD PREPARATION. Magnified 170 diameters. (Szymonowicz.)

and around the intrafusal muscle-fibres (figs. 278, 279, 280), which they clasp by flattened encircling branches (*annulo-spiral endings*). Other, much finer, medullated fibres pass to the spindle and terminate in neighbouring parts of the intrafusal bundles in flower-like or plate-like expansions (fig. 279). According to some observers these fine fibres are prolonged from the annulo-spiral endings of the coarser fibres; but Dogiel states that they run independently to the intrafusal bundle. No motor nerve-fibres appear to pass into the spindles, unless the fine fibres above mentioned are to be so regarded, nor do the muscle-fibres of the spindle undergo atrophy on section of the motor nerve-roots, as is the case eventually with the ordinary muscle-fibres. It is not uncommon to find two or three spindles near one another or even enclosed in a common sheath. Muscle-spindles have not yet been found in the muscles of the tongue, but otherwise their occurrence is general.

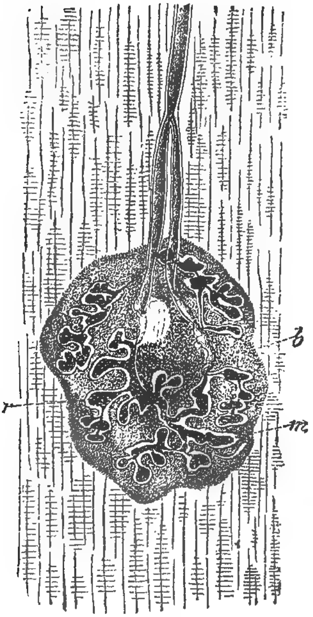

FIG. 284.—MOTOR END-ORGAN OF A LIZARD. GOLD PREPARATION. (Kühne.)

n, nerve-fibre dividing as it approaches the end-organ; *r*, ramification of axis-cylinder upon *b*, granular bed or sole of the end-organ; *m*, clear substance surrounding the ramification of the axis-cylinder.

In the frog both motor and sensory nerves may terminate in and between the same muscle-fibres, but at different parts of the fibre.

Another kind of ending of sensory fibres in muscle has been described by Ceccherelli, in the form of an arborisation of nerve-fibrils around the ends of the muscle-fibres which are inserted into tendon (fig. 281).

Ending of motor-nerves.—The motor-nerves to muscles terminate in fine ramifications of the axis-cylinder; in striated (voluntary) muscles the ramification is localised in special organs termed *motor end-organs*, or less correctly, *end-plates*.

In **voluntary muscle**, the nerves, which are large and medullated, terminate, as is just stated, in special end-organs (figs. 282 to 285). A medullated fibre will branch two or three times before ending, and then each branch passes straight to a muscular fibre. Having reached this, the neurolemma of the nerve-fibre is continued into the sarcolemma of the muscle, the medullary sheath stops short, and the axis-cylinder ends in a close terminal ramification with varicose expansions upon its branches. This ramification is embedded in a layer of granular nucleated protoplasm (*sole*) (fig. 284, *b*), probably a development of the sarcoplasm of the muscle. In some cases the ramification is restricted to a small portion of the muscular fibre, and forms with the granular bed a slight prominence (*eminence of Doyère*). This is the case in insects and mammals. In lizards the ramification is rather more extended than in mammals, whilst in the frog it is spread over a considerable length of the fibre. The ramification shows a fibrillar structure, when appropriately fixed and stained (fig. 285). In mammals there appears to be only one end-plate to each fibre; in reptiles there may be several. The end-plate is covered, externally to the sarcolemma, by an expansion of the sheath of Henle of the nerve-fibre (*telolemma*).

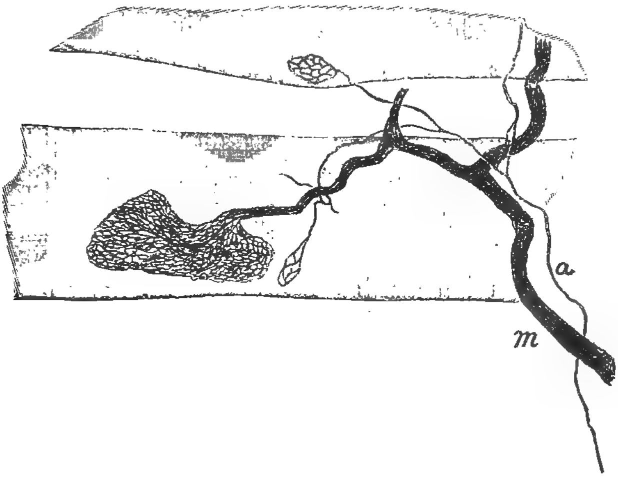

Fig. 285.—Muscle-fibres of mouse with fine non-medullated fibres ending in small expansions near the end-plates. (Boeke.) Magnified 1800 diameters.
m, medullated fibre; *a*, accessory fibre.

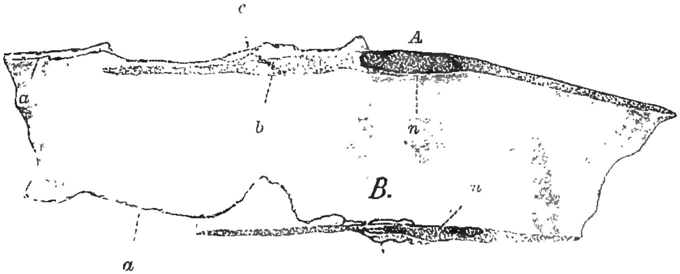

Fig. 286.—Ending of nerve-fibrils over plain muscle-cells. (Huber and de Witt.)
a, fibrils passing to their termination; *b*, a terminal fibril; *c*, a branch passing to another muscle-cell; *n*, nuclei of cells.

Besides the medullated nerve-fibre with its end-plates many if not all muscle-fibres receive an accessory non-medullated nerve-filament which also ends in a fibrillar expansion at the surface of the fibre (fig. 285). These filaments do not degenerate of the motor nerve is cut before it receives fibres from the sympathetic (Boeke).

In **involuntary muscle**, both plain and cardiac (figs. 286, 287), the nerve-fibres, which near their termination are entirely non-medullated, end in plexuses. The primary plexuses are generally furnished with ganglion-cells in abundance. Such gangliated plexuses are best developed in the wall of the intestine. From the cells of these plexuses other nerve-fibres pass which form secondary plexuses and terminal ramifications amongst the contractile fibre-cells, to the surface of which the endings of the branches, often slightly enlarged, are applied (Huber and de Witt). Boeke, however, finds (in the ciliary muscle) that the terminal fibrils pass *into* the muscle-cells, ending within them in loop-like expansions.

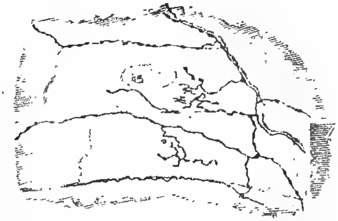

FIG. 287.—ENDING OF NERVE-FIBRES IN CARDIAC MUSCLE. (Smirnow.)

LESSON XX.

STRUCTURE OF THE LARGER BLOOD-VESSELS.

1. Sections of a medium-sized peripheral artery and vein, *e.g.*, popliteal or radial. In this preparation the limits of the vascular coats can be well seen and also the differences which they present in the arteries and veins respectively. The sections may be stained with hæmatoxylin and eosin or with orcein, and mounted in dammar.

2. Mount in dammar a thin slice cut from the inner surface of a large artery which, after having been cut open longitudinally and washed with distilled water, has been rinsed first with nitrate of silver solution and subsequently with distilled water and exposed for a minute or two to sunlight. It should then be hardened in alcohol. This preparation will show the outlines of the endothelium-cells which line the vessel. A similar preparation may be made from a large vein.

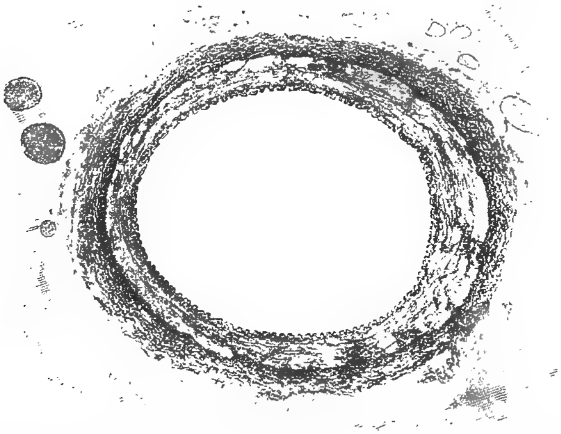

Fig. 288.—Section of renal artery of dog. (G. Mann.) Low power photograph.

The elastic layer of the thin inner coat is thrown into corrugations by the post-mortem contraction of the middle coat. The distinction between middle coat and adventitia is well shown. Some branches of the renal nerves are seen, cut across, in the tissue around the artery.

3. A piece of an artery which has been macerated for some days in 33 per cent. alcohol is to be teased so as to isolate some of the muscular cells of the middle coat and portions of the elastic layers (networks and fenestrated membranes) of the inner and middle coats. The tissue may be stained cautiously with diluted hæmatoxylin, and glycerine afterwards added. The muscular cells are recognisable by their long rod-shaped nuclei; they often have an irregular outline. Sketch one or two and also a piece of the elastic network or fenestrated membrane. The fenestrated membrane is best obtained from one of the arteries of the base of the brain; it is also well seen in the arteries within the kidney.

4. Transverse sections of aorta and carotid. Notice the preponderance of elastic tissue in these compared with ordinary peripheral arteries.

5. Transverse section of vena cava inferior. Notice the comparatively thin layer of circular muscle, and outside this the thick layer of longitudinal muscular bundles in the adventitia.

Make sketches from 1, 4, and 5 under a low power, from 2 and 3 under a high power.

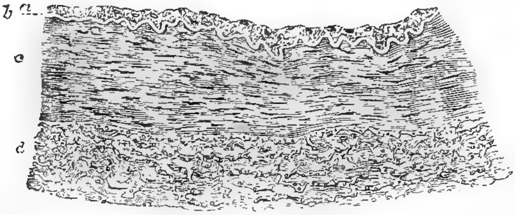

FIG. 289.—TRANSVERSE SECTION OF PART OF THE WALL OF THE POSTERIOR TIBIAL ARTERY. 75 diameters.

a, endothelial and subendothelial layers of inner coat; *b*, elastic layer (fenestrated membrane) of inner coat, appearing as a bright line in section; *c*, muscular layer (middle coat); *d*, outer coat, consisting of connective-tissue bundles. In the interstices of the bundles are some connective-tissue nuclei, and, especially near the muscular coat, a number of elastic fibres cut across.

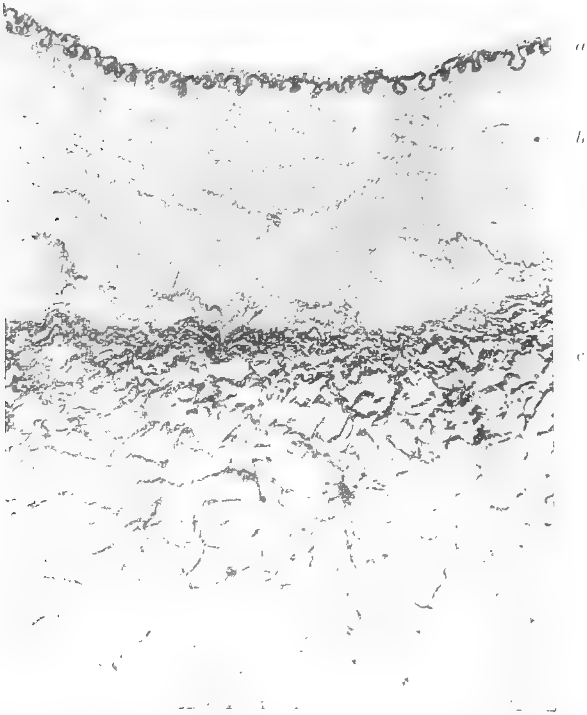

FIG. 290.—SECTION OF RENAL ARTERY STAINED WITH ORCEIN TO SHOW THE DISTRIBUTION OF THE ELASTIC TISSUE. Magnified 200 diameters.

a, inner coat; *b*, middle coat; *c*, adventitia.

An **artery** is usually described as being composed of three coats, an *inner* or elastic, a *middle* or muscular, and an *external* or areolar (figs. 288, 289, 290). It is, however, more correct to describe the wall of an artery as being mainly composed of muscular and elastic tissue, lined internally by a pavement epithelium (*endothelium*), and strengthened externally by a layer of connective tissue (*adventitia*).

The *inner coat* (*tunica intima*) is lined by a thin layer of *pavement epithelium* (*endothelium*), the cells of which are somewhat elongated in the direction of the axis of the vessel (fig. 291), and form a smooth lining to the tube. After death they become easily detached.

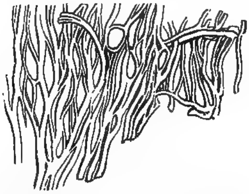

FIG. 292.—ELASTIC NETWORK OF ARTERY. (Toldt.)

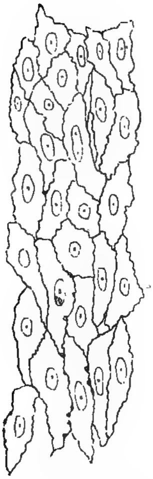

FIG. 291.—EPITHELIAL LAYER LINING THE POSTERIOR TIBIAL ARTERY. 250 diameters.

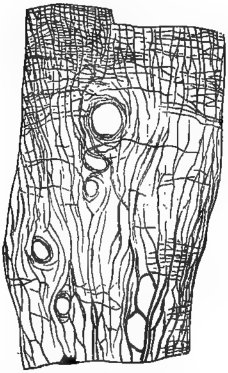

FIG. 293.—PORTION OF FENESTRATED MEMBRANE OF HENLE FROM AN ARTERY. (Toldt.)

The endothelium is the essential layer in all blood-vessels. It is always the first part to be developed, and in some it remains as the only layer of the vessel. This is the case with all true capillaries and with certain veins, and also with the lacunar spaces or *sinusoids*, which, as Minot has pointed out, take the place of capillaries in certain parts (*e.g.* in the liver, the medulla of the suprarenal capsules and the Wolffian body of the embryo); it is also true of the sinuses of erectile tissue, as well as the sinus-like blood-vessels which are met with in invertebrates. In some structures the endothelial layer of the blood-vessels is imperfect, viz.: in the capillaries and blood-sinuses of the spleen, the placental mucous membrane of the pregnant uterus, and the sinusoids (capillaries) of the liver; in these places the blood finds its way into the interstices of the organ and comes in direct contact with the tissue-cells.

Next to the endothelium comes an elastic layer in the form either of *elastic networks* (fig. 292) or of a *fenestrated membrane* (figs. 293, 294). In some arteries there is a layer of fine connective tissue intervening between the endothelium and the fenestrated membrane (*subendothelial layer*) (fig. 295).

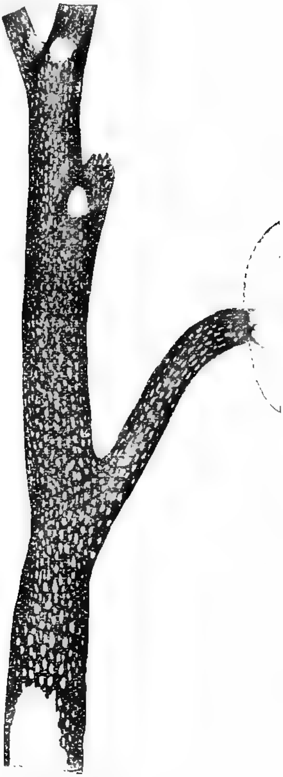

Fig. 294.—Fenestrated membrane of one of the cortical branches of the renal artery. (Mann.)

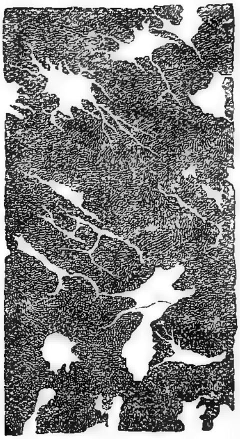

Fig. 295.—Subendheotlial layer of artery stained with silver nitrate.

The *middle coat* (*tunica media*) consists mainly of circularly disposed plain muscular fibres, but it is also pervaded in most arteries by a network of elastic fibres which are connected with the fenestrated membrane of the inner coat and are sometimes almost as much developed as the muscular tissue itself. This is especially the case with the largest arteries, such as the aorta and carotid and its immediate branches, whereas in the smaller arteries of the limbs the middle coat is composed almost purely of muscular tissue. The muscular fibres are comparatively short, with long rod-shaped nuclei

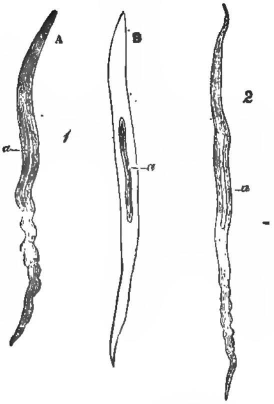

Fig. 296.—Muscle-cells of artery. (Kölliker.)

B, after treatment with acetic acid; *a*, nucleus.

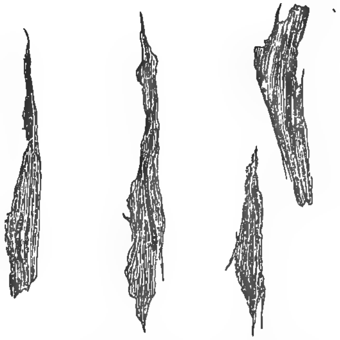

Fig. 297.—Muscular fibre-cells from superior thyroid artery. 340 diameters.

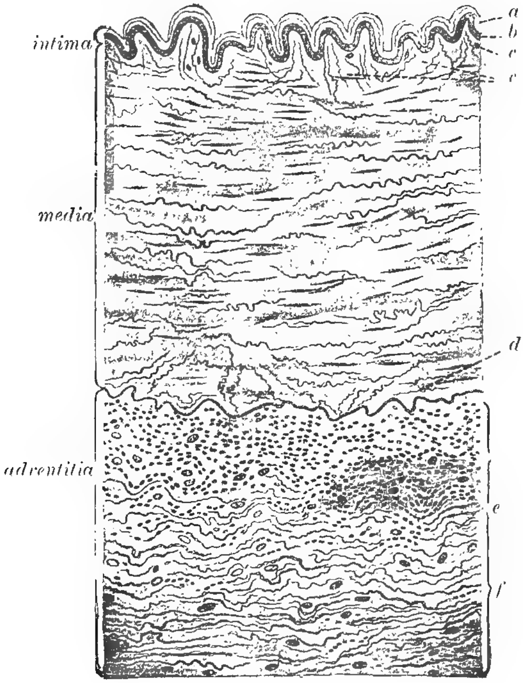

Fig. 298.—Section of the lingual artery. (Grünstein.)

a, endothelium and subendothelial layer of inner coat; *b*, its elastic layer; *c*, *c*, *d*, innermost and outermost layers of middle coat, with elastic fibres passing obliquely to join the elastic layers which bound that coat; *e*, innermost part of outer coat or adventitia, showing many elastic fibres cut across; *f*, outer part of adventitia.

(fig. 296), and are often irregular in shape (as in fig. 297), especially if the middle coat contains much elastic tissue.

The *outer coat* is formed of connective tissue with a good many elastic fibres, especially next to the middle coat (figs. 290, 298). The strength of an artery depends largely upon this coat; it is far less easily cut or torn than the other coats, and it serves to resist undue expansion of the vessel. Its outer limit is not sharply marked, for it tends to blend with the surrounding connective tissue; hence it has been termed *tunica adventitia.*

Variations in different arteries. The *aorta* (figs. 299, 300) differs in some respects in structure from an ordinary artery. Its inner coat contains a considerable thickness of subendothelial connective tissue, and its elastic tissue is chiefly composed of fine fibres, not especially marked off from those of the middle coat, so that the inner and middle coats appear blended with one another. On the other hand, there is a very great development of elastic tissue in the middle coat, forming membranous layers which alternate with layers of the muscular tissue. A good deal of connective tissue also takes part in the formation of the middle layer, making this coat unusually strong. The middle coat constitutes almost the entire thickness of the wall, the inner and outer coats being relatively thin.

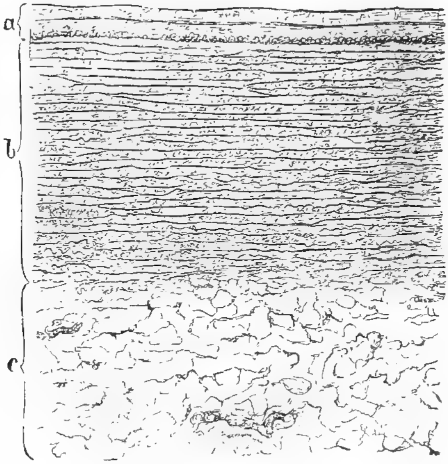

FIG. 299.—SECTION OF THORACIC AORTA AS SEEN UNDER A LOW POWER. (Toldt.)

a, the inner coat consisting of three layers, viz.: 1. Endothelium seen as a fine line. 2. Subendothelial layer. 3. Elastic layers. In the outer part of the inner coat, at its junction with the middle, a layer of longitudinal muscular fibres is represented as cut across. *b*, middle coat with alternating layers of muscle and elastic tissue; *c*, outer coat with two vasa vasorum.

Apart from the relative amount of elastic tissue which has been already referred to, the variations which occur in the arterial system have reference chiefly to the development and arrangement of the muscular tissue. Thus in many of the larger arteries there are a few longitudinal muscular fibres at the inner boundary of the middle coat, and in some arteries amongst the circular fibres of the middle coat. This is the case in the aorta. In the part of the umbilical arteries within the umbilical cord there is a complete layer of longitudinal fibres internal to the circular fibres and another external to them, whilst the amount of elastic tissue is very small. Longitudinal fibres are also present in some other arteries (iliac, superior mesenteric, splenic, renal, etc.), external to the circular fibres, and therefore in the outer coat of the artery.

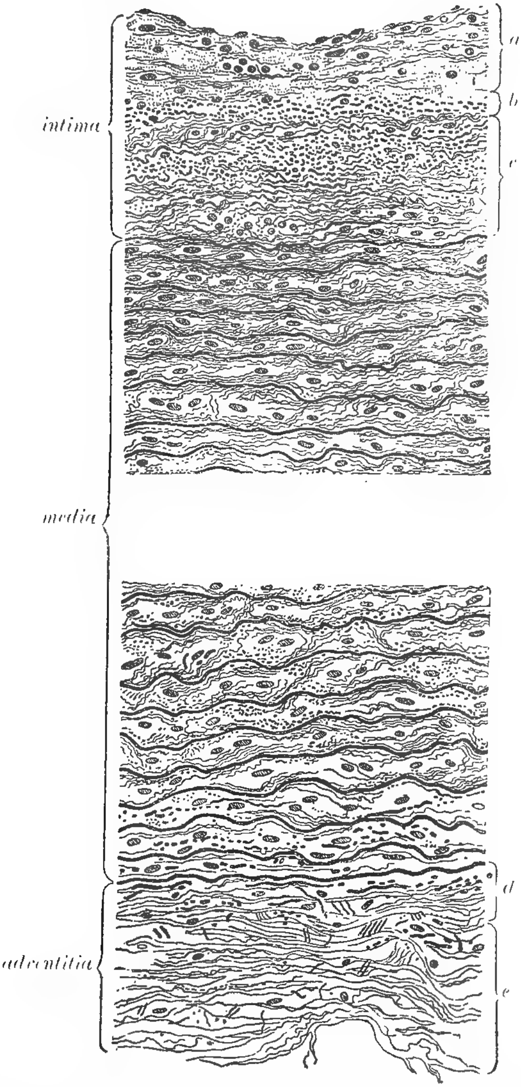

FIG. 300.—SECTION OF AORTA MORE MAGNIFIED. (Grünstein.)
a, endothelial and subendothelial layers of inner coat; *b*, *c*, outer layers of inner coat containing many fine elastic fibres; *d*, *e*, parts of outer coat.

The **veins** (fig. 301) on the whole resemble the arteries in structure, but they exhibit certain differences. In the *internal coat* (*a*, *b*) the same layers may be present, but the elastic tissue is less developed, and may be quite inconspicuous; it seldom takes the form of a complete membrane. The epithelium (endothelium) cells are less elongated than those of the arteries. The *middle coat* (*c*) contains less elastic tissue and also much less muscular tissue, being partly occupied by bundles of white connective-tissue fibres. These are continuous with those of the external coat (*d*), which is relatively better developed in the veins than in the arteries, so that, although thinner, their walls are often stronger.

Many of the veins are provided with *valves*, which are crescentic folds of the internal coat strengthened by a little fibrous tissue: a few muscular fibres may be found in the valve near its attachment. The layer of the inner coat is rather thicker and the endothelium-cells are more elongated on the side which is subject to friction from the current of blood than on that which is turned towards the wall of the vessel.

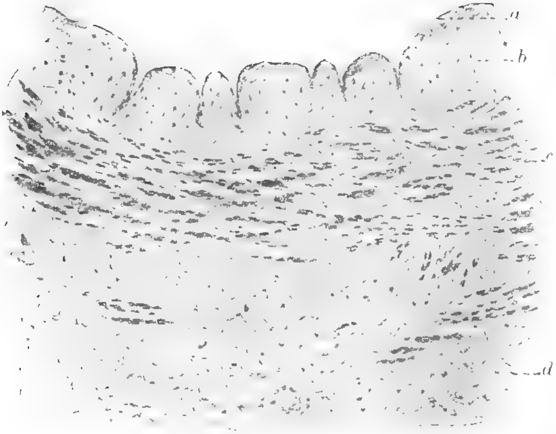

FIG. 301.—TRANSVERSE SECTION OF PART OF THE WALL OF ONE OF THE POSTERIOR TIBIAL VEINS (MAN). About 200 diameters.

a, endothelial, and *b*, subendothelial layers of inner coat; *c*, middle coat consisting of irregular layers of muscular tissue, alternating with connective tissue, and passing somewhat gradually into the outer connective-tissue coat, *d*.

Variations in different veins.—The veins of different parts vary considerably in structure. In many veins longitudinal muscular fibres are found in the inner part of the middle coat, as in the iliac, femoral, umbilical; the umbilical vein within the umbilical cord having three muscular layers like the corresponding arteries; it has also a well-developed internal elastic layer. In other veins, longitudinal fibres occur external to the circularly disposed fibres, and may be described as belonging to the outer coat. This is the case with the abdominal, and especially the hepatic, portions of the inferior vena cava (fig. 302), and to a less extent with the hepatic veins and the portal vein and its tributaries. In the superior vena cava, in the upper part of the inferior vena cava and in the jugular, subclavian, and innominate veins muscular fibres are almost entirely absent in the middle coat, and there are but few in the adventitia. The veins of the pia mater, brain and spinal cord, retina, and bones, and the venous sinuses of the dura mater and placenta have no muscular tissue.

It is only the larger veins, especially those of the limbs, that possess valves. They are wanting in many of the veins of the viscera (although occurring abundantly in some of the tributaries of the portal vein), in those within the cranium and vertebral canal, in the veins of the bones, and in the umbilical vein.

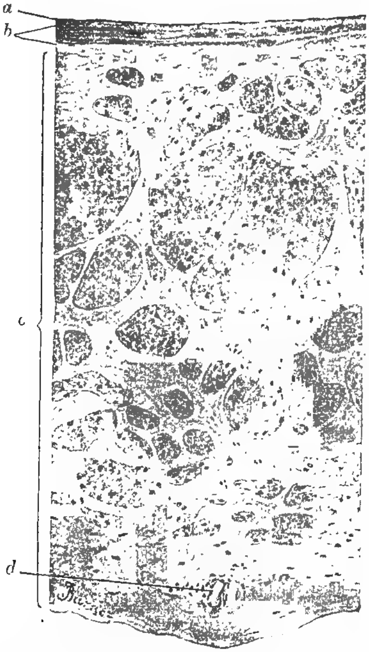

FIG. 302.—TRANSVERSE SECTION OF THE INFERIOR VENA CAVA OF THE DOG. (Szymonowicz.) Magnified 150 diameters.

a, intima; b, thin layer of circular muscle; c, thick adventitia with longitudinal muscular bundles; d, a vas vasis.

LESSON XXI.

SMALLER BLOOD-VESSELS AND LYMPH-VESSELS, SEROUS MEMBRANES. MICROSCOPIC STUDY OF THE CIRCULATION. DEVELOPMENT OF BLOOD-VESSELS.

1. Take a piece of pia mater which has been fixed with 2 per cent. bichromate of potassium and stained with hæmatoxylin or carmine and separate from it some of the small blood-vessels of which it is chiefly composed. Mount the shreds in dilute glycerine, or after dehydrating with alcohol and passing through clove oil they can be mounted in dammar. The structure of the small arteries can be studied in this preparation, the nuclei of the endothelium and of the muscular coat being brought distinctly into view by the stain. The veins of the pia mater possess no muscular tissue. Capillary vessels which have been dragged out from the brain in removing the pia mater may also be seen in this preparation. Sketch two small arteries of different sizes, giving also their measurements.

2. Mount in dammar a piece of the omentum of the rabbit, stained with silver nitrate. The membrane should be stretched over a cork or a ring of wood or vulcanite. Or it may conveniently be fixed by spreading it over a glass plate, and having brought its margins round the edges of the plate, place another plate of the same size at the back, and bind the plates together by a couple of rubber bands; the exposed surface can then be treated in the following way: Rinse with distilled water, cover for five minutes with 1 per cent. nitrate of silver solution, again wash with distilled water and expose to sunlight in water. When slightly browned, the preparation is removed from the light. Pieces may now be cut off from the membrane, floated flat on a slide, allowed to dry completely and mounted in dammar; they should include one or more blood-vessels. Or the glass plate with the omentum stretched over it may be dehydrated with alcohol and cleared with clove oil before cutting off pieces to be mounted in dammar. It is easier to cut up after treatment with clove oil.

The preparation is intended to show the endothelium of the smaller blood-vessels and accompanying lymphatics, and also the endothelium of the serous membrane. Sketch a small piece showing these structures.

3. Mount in dammar a piece of the central tendon of the rabbit's diaphragm which has been prepared with silver nitrate, the pleural surface having been first brushed to remove the serous endothelium and thus enable the nitrate of silver more readily to penetrate to the network of underlying lymphatic vessels. Observe the lymphatic plexus under a low power; sketch a portion of the network. If the peritoneal surface is focussed, the endothelium which covers that surface will be seen, and opposite the clefts between the radially disposed tendon-bundles stomata may be looked for in this endothelium.

4. Examine sections of the thoracic duct. These are made in the same way as sections of the blood-vessels.

5. Stomata.—Open the abdomen of a freshly killed frog, preferably a male, and remove the abdominal viscera, taking care not to injure the membrane or septum at the back of the abdomen, which lies over and between the kidneys and separates the peritoneal cavity from the *cisterna lymphatica magna*, a large lymph-space in which the aorta and vena cava are contained. Cut out the kidneys along with as much as possible of the above septum; rinse with distilled water; and

place in a watch-glass of 1 per cent. silver nitrate for one minute. Rinse again in distilled water and expose in tap water to the light. When slightly browned snip off a portion of the membranous septum, float it flat on a slide, drain off the superfluous water and allow it to dry; then add a drop of dammar and cover the preparation.

6. Kill a frog by destroying the brain and study the circulation of the blood in the mesentery. It can also be studied in the web of the frog's foot, in the lung and tongue of the frog or toad and in the tail of the tadpole or of any small fish. For observing the phenomena attending commencing inflammation and the emigration of leucocytes from the vessels, the mesentery is the most convenient object. The frog can be immobilised with curari or by placing it in water in which chloroform or ether has been shaken up: a lateral incision is made in the abdominal wall, a loop of intestine drawn out, and laid over a ring of cork which is fixed to a glass or cork plate (fig. 303). The membrane must be kept wet with Ringer's solution.[1]

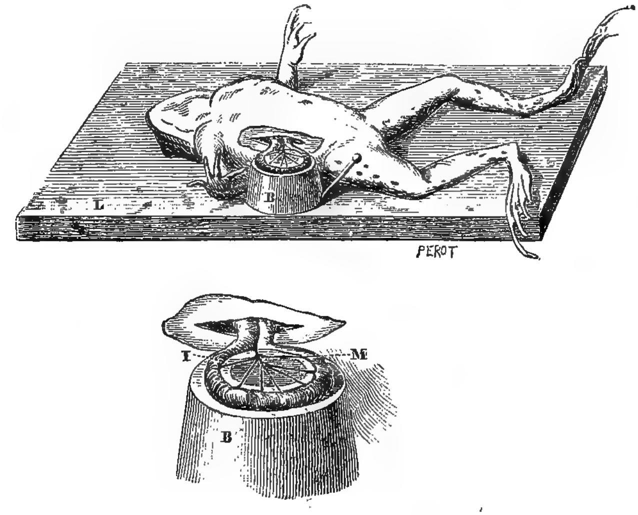

FIG. 303.—METHOD OF STUDYING THE CIRCULATION IN THE FROG'S MESENTERY. (Ranvier.)

L, cork or glass plate; *B*, perforated cork, the aperture in which is closed by a circular glass cover (not too thin); *M*, mesentery laid over the glass cover. The brain is destroyed and the animal then immobilised with curari.

7. The arrangement of the blood-vessels in the various tissues and organs is studied in injected preparations (see Appendix for methods of injection).

THE SMALLER BLOOD VESSELS.

The coats of the **small arteries and veins** are much simpler in structure than those of the larger vessels, but they contain at first all the same elements. Thus there is a lining endothelium and an elastic layer, the two together forming an *inner coat*; a *middle coat* of circularly disposed plain muscular tissue; and an *adventitia.* The same differences are found between the smaller arteries and veins as with the larger, the walls of the veins being thinner and containing far less muscular tissue (fig. 304); and the lining epithelium-cells, much elongated in both vessels, being far longer and narrower in the small arteries than in the corresponding veins (fig. 305).

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[1] For details of the methods used in studying the circulation in different parts, see the author's *Course of Practical Histology*.

In the smallest vessels it will be found that the elastic layer has entirely disappeared in the veins, and the muscular tissue is considerably reduced in thickness in both kinds of vessel. Indeed, it is soon represented by but a single layer of contractile cells, and even these no longer form a complete layer. By this time also, the outer coat as well as the elastic layer of the inner coat have disappeared both from arteries and veins. The vessels are reduced, therefore, to the condition of a tube formed of endothelium-cells, with a partial covering of circularly disposed muscle-cells.

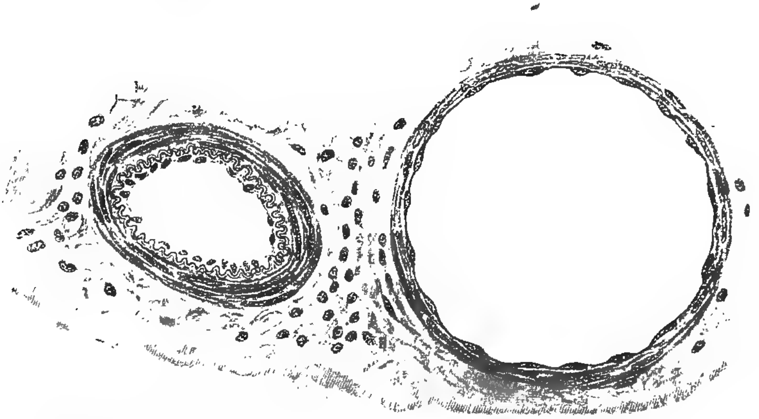

FIG. 304.—TRANSVERSE SECTION OF A SMALL ARTERY AND VEIN. Magnified 250 diameters.

Even in the smallest vessels which are not capillaries the differences between arteries and veins are still manifested. These differences may be enumerated as follows: The veins are larger than the corresponding arteries; they branch at less acute angles; their muscle-cells are fewer, and their endothelium-cells less elongated; the elastic layer of the inner coat is always less marked, and disappears sooner as the vessels become smaller.

Capillary vessels.—When traced to their smallest branches the arteries and veins are eventually seen to be continued into a network of the smallest blood-vessels or capillaries. The walls of these are composed only of flattened epithelium-cells (fig. 306) continuous with those that line the arteries and veins; these cells can be exhibited by staining a tissue with nitrate of silver. The cell-outlines are not shown in developing capillaries; in these, silver nitrate shows no elective staining. This is the case also with the capillaries of the villi, those of the choroid coat of the eye (Eberth), and those of the kidney-glomeruli (Ranvier): in all these places the walls are formed of a syncytium.

The capillaries vary somewhat in size and in the closeness of their meshes; their arrangement in different parts, which is mainly determined by the disposition of the tissue-elements, may best be studied in injected preparations, and will be described when the structure of the several organs is considered.

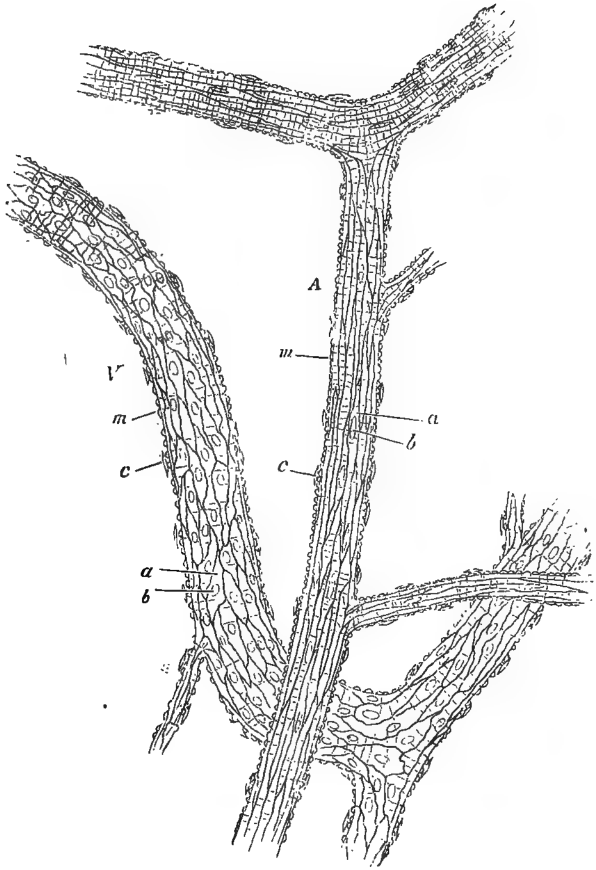

FIG. 305.—A SMALL ARTERY, *A*, AND VEIN, *V*, FROM THE SUBCUTANEOUS CONNECTIVE TISSUE OF THE RAT, TREATED WITH NITRATE OF SILVER, WITH SUBSEQUENT STAINING OF NUCLEI. 175 diameters.

a, *a*, endothelial cells with *b*, *b*, their nuclei; *m*, *m*, transverse markings due to staining of substance between the muscular fibre-cells; *c*, *c*, nuclei of connective-tissue corpuscles attached to exterior of vessel.

Usually the arterioles pass gradually into the capillary network and the capillaries unite to form small veins which, on receiving others, gradually increase in size. But in certain situations the arrangement is different. Thus in the spleen the arterial capillaries have imperfect walls and the blood passes into the interstices of the reticular tissue of the organ, from which it is collected by sinus-like veins which also have incomplete walls. In erectile tissue the arterioles open, without the medium of capillaries, into large cavernous spaces bounded by fibrous and plain muscular tissues and lined by endothelium: the veins lead out of these spaces, so that there are no true capillaries, except such as are distributed to the tissues which form the walls of the spaces. In the sympathetic ganglia, as shown by Ranvier (fig. 307), the capillaries open abruptly into large sinus-like venules. And in the liver and a few other organs, as will presently be explained, the connexion between afferent and efferent vessels is effected, not by true capillaries, but by sinus-like spaces between the tissue-elements ("sinusoids" of Minot).

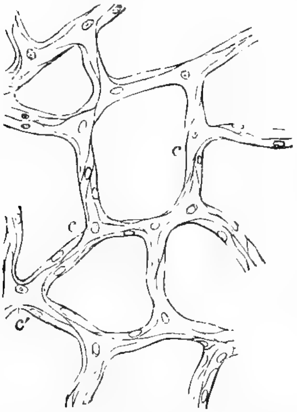

FIG. 306.—CAPILLARY VESSELS FROM THE BLADDER OF THE CAT, MAGNIFIED.

The outlines of the cells are stained by nitrate of silver.

In the transparent parts of animals, the blood may be seen flowing through the capillary network from the arteries into the veins (fig. 308). The current is very rapid in the small arteries, somewhat less rapid in the veins, and slow in the capillaries. The flow in any vessel is fastest in the centre, slowest nearest the wall (inert layer). In this layer the leucocytes are carried along by the stream and may be observed—especially

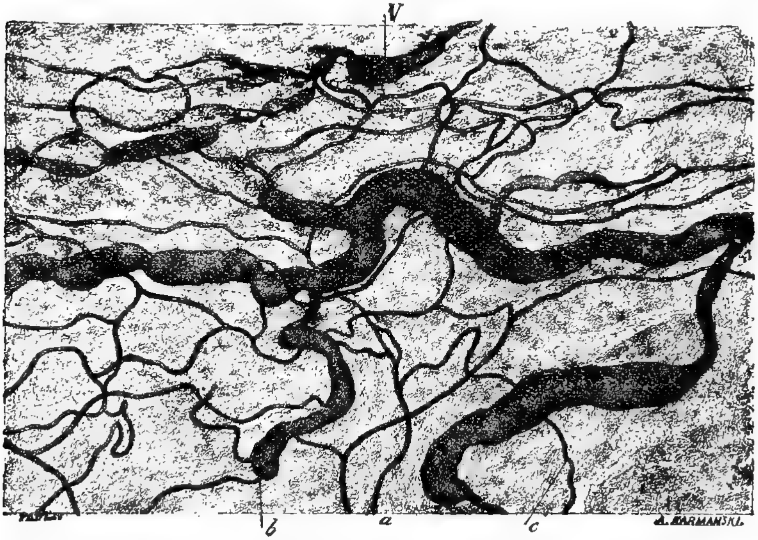

FIG. 307.—VESSELS IN A SYMPATHETIC GANGLION OF THE RABBIT INJECTED. (Ranvier.)

a, arterioles; *b*, *c*, capillaries; *V*, sinus-like veins.

where there is commencing inflammation of the part, as in the mesentery in consequence of exposure—to adhere to the inner surface of the blood-vessel, and here and there to pass through the coats of the small vessels, and appear as *migratory cells* in the surrounding connective tissue (fig. 309). The blood-platelets are also to be seen in the inert layer, and in commencing inflammation show a tendency to adhere to the wall and to one another.

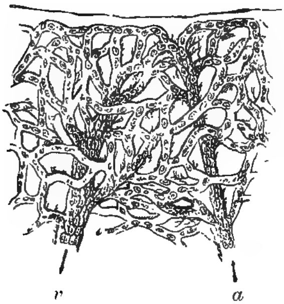

FIG. 308.—BLOOD-VESSELS IN THE WEB OF THE FROG'S FOOT SHOWING AN ARTERIOLE COMMUNICATING THROUGH THE CAPILLARY NETWORK WITH A VENULE. (Allen Thomson.)

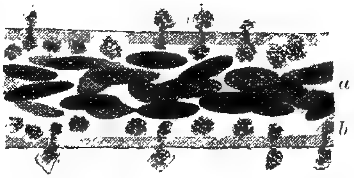

FIG. 309.—BLOOD FLOWING THROUGH A SMALL VEIN OF THE FROG'S MESENTERY.

The mesentery had been exposed for a short time, so that there was commencing inflammation and many of the white corpuscles are observed sticking to the side of the vessel and even passing through the vascular wall. *a*, central rapid layer containing the coloured corpuscles; *b*, outer slower layer (inert layer) containing the white corpuscles.

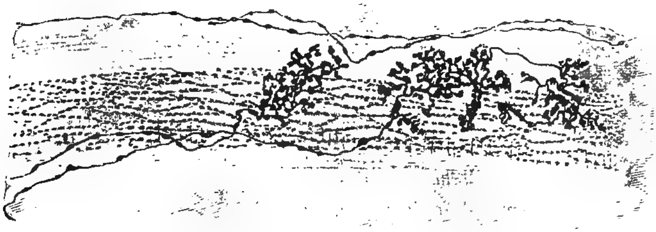

FIG. 310.—ENDING OF SENSORY NERVE-FIBRES IN ARBORESCENCES IN THE WALL OF A SMALL ARTERY. (Dogiel.)

The intercellular substance between the endothelium-cells is shown by dotted lines and the outlines of the muscular fibres are here and there faintly indicated.

Vessels and nerves of blood-vessels.—The larger arteries and veins possess blood-vessels (*vasa vasorum*) and lymphatics, both of which ramify chiefly in the external coat. Nerves are distributed to the muscular tissue of the middle coat, after forming a plexus in the outer coat. Most of the nerves are non-medullated. But there are a certain number of medullated fibres intermingled with the non-medullated and passing to end in localised arborescences (fig. 310) partly in the adventitia, partly in the intima. These medullated fibres are doubtless afferent; the majority of the non-medullated are probably efferent (vaso-motors). In the aorta of man and in some of the larger animals Pacinian corpuscles are here and there met with in the adventitia. The capillary vessels also receive nerve-fibres (fig. 311), which form a fine plexus of fibrils in close contact with the endothelium-cells of which the walls of these vessels are composed.

DEVELOPMENT OF BLOOD-VESSELS.

The heart and blood-vessels show themselves very early. They are always developed in connective tissue or in the mesenchyme which precedes it, the first vessels being found in the vascular area which surrounds the early embryo. Their development there may be studied in the embryo chick or mammal, and also in the omentum of the new-born rabbit, or in the serous membranes and subcutaneous connective tissue of fœtal animals. The cells which are to form the vessels (*vasoformative cells*) branch and unite with one another to form a syncytium, and cavities form in this and extend into the branches. In the meantime the nuclei multiply and become distributed along the branches, cell-areas being at a later stage marked out around the nuclei. In this way intercommunicating vessels—capillaries in which blood-corpuscles may have become also developed (see p. 43)—are produced (fig. 312). These presently become connected with previously formed vessels, which extend themselves by sending out sprouts, at first solid, and afterwards hollowed out. Even the larger blood-vessels appear first to be developed in the same way as the capillaries, in so far that the epithelium is first formed and the muscular and other tissues are subsequently added; but whether they are formed as clefts in the mesoblastic tissue, which become bounded by flattened cells, or whether as a hollowed-out syncytium, has not been definitely ascertained.

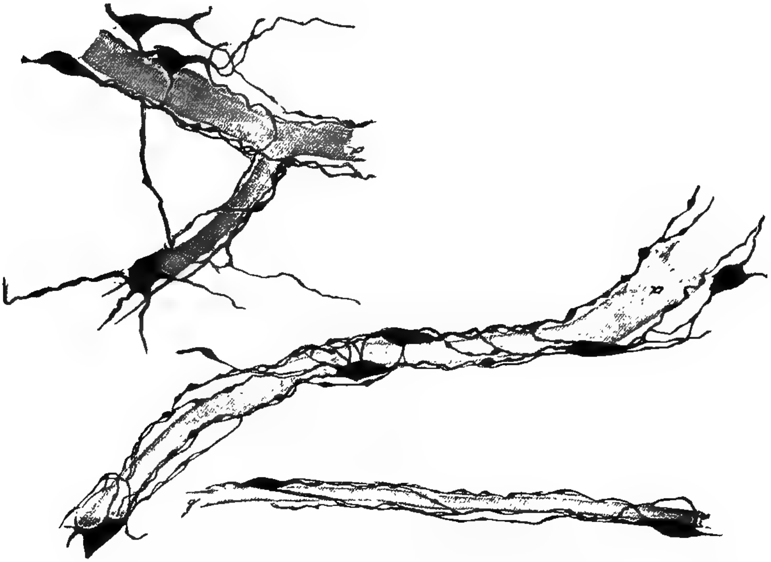

FIG. 311.—ENDING OF NERVE-FIBRILS ON CAPILLARY VESSELS. (Dogiel.)

Many authors consider that new blood-vessels are exclusively formed by sprouts from pre-existing vessels, and regard the appearances above described as being due to retrogressive development of an already formed vascular network (see p. 45).

SINUSOID VESSELS.

These are sinus-like blood-spaces between the cells of certain tissues (Minot, Lewis). They may when fully developed bear a superficial resemblance to blood-capillaries, but differ essentially from these in their mode of development, as well as in their relationship to the connective tissue, and to the tissue elements of the organs in which they occur. For, whereas capillary blood-vessels are developed amongst and between the tissue-elements and are connected with or grow from neighbouring capillaries which are themselves surrounded by areolar tissue, sinusoids make their first appearance in the form of comparatively large blood-spaces connected with the venous (or arterial) system. Into these spaces, the walls of which are formed only of a single layer of endothelial cells, the tissue-elements of the developing organ

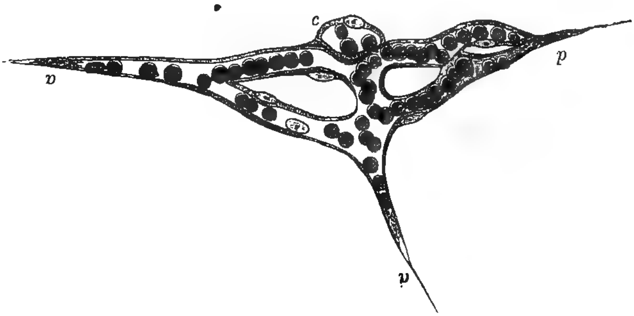

FIG. 312.—ISOLATED CAPILLARY NETWORK FORMED BY THE JUNCTION OF A HOLLOWED-OUT SYNCYTIUM, CONTAINING COLOURED BLOOD-CORPUSCLES IN A CLEAR FLUID

c, a hollow cell the cavity of which does not yet communicate with the network; p, p, pointed processes, extending in different directions for union with neighbouring capillaries.

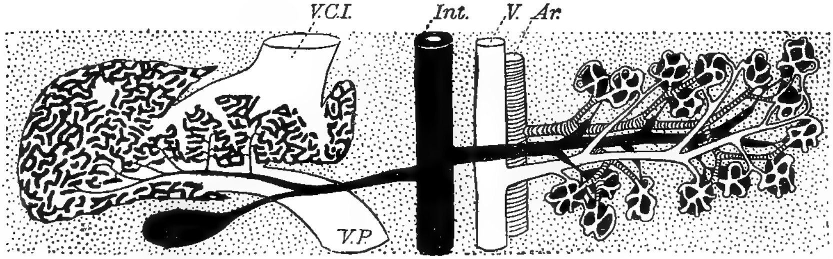

FIG. 313.—DIAGRAM TO ILLUSTRATE THE DEVELOPMENT OF BLOOD-CAPILLARIES (RIGHT SIDE), AND SINUSOIDS (LEFT SIDE) RESPECTIVELY. (F. T. Lewis.)

Int, intestinal entoderm with outgrowth on the left to form the liver and gall-bladder, and on the right to form the pancreas. *V.C.I.*, vena cava inferior; *V.P.*, vena portæ; *V*, vein, and *Ar*, artery supplying pancreas. It is seen that the sinusoids or apparent capillaries of the liver are formed by the breaking up of a large blood-space into channels by the growth into it of cell-columns derived from the hepatic outgrowth of the entoderm.

(Wolffian body, liver, suprarenals, blood-glands, etc.) grow, invaginating the thin wall and forming cell-trabeculæ within the sinus (fig. 313), so that the cells of the organ are directly in contact with the invaginated endothelium, and are only separated by this from the blood contained within the sinus. But the connexion may be yet closer than this, for, as happens in the liver, the invaginated endothelium may become defective, so that the blood within the sinus comes into actual contact with the cells of the organ, and runs into the interstices between them. As development proceeds these interstices come to resemble blood-capillaries in general arrangement; but the resemblance is only superficial, and the intimate relationship between the blood and the tissue-elements, which are both enclosed within the original sinus, is usually maintained.

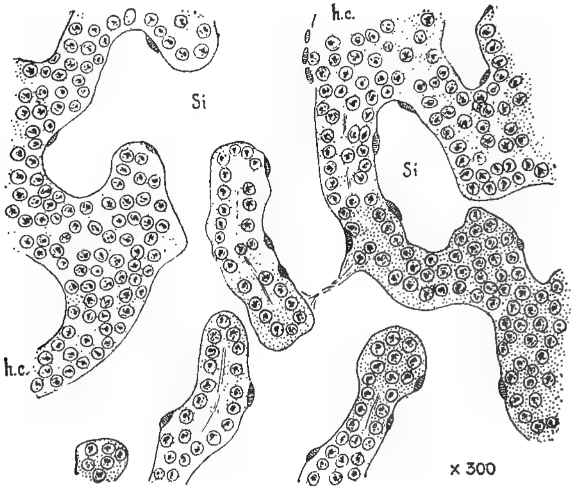

FIG. 314.—DEVELOPING LIVER OF CHICK, TO SHOW HOW THE HEPATIC CYLINDERS ENCROACH ON THE LUMINA OF THE SINUS-LIKE VEINS AND BREAK THEM UP ULTIMATELY INTO THE CAPILLARY-LIKE CHANNELS CALLED SINUSOIDS. (Minot.)
h.c., hepatic cylinders; *Si*, sinusoids.

LYMPHATICS OR LYMPH-VESSELS.

To the lymphatic system belong not only the *lymph-vessels* and *lymph-glands*, but also the *cavities of the serous membranes*, which are moistened with lymph and are in open communication with lymph-vessels which run in their parietes.

The larger **lymph-vessels** somewhat resemble the veins in structure (fig. 316), except that their coats are much thinner and valves much more numerous. In lymphatics of smaller size, which in the fresh condition

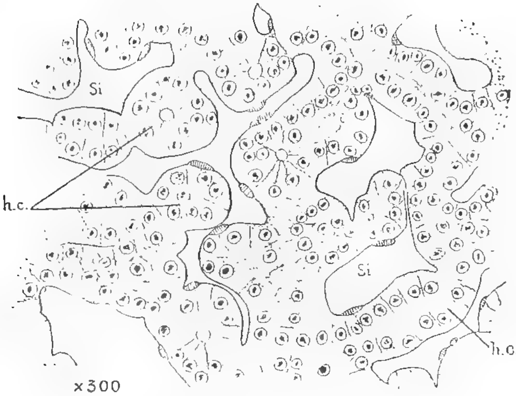

FIG. 315. LIVER OF EMBRYO CHICK OF ELEVEN DAYS. (Minot.)
h.c., hepatic cylinders; *Si*, sinusoids.

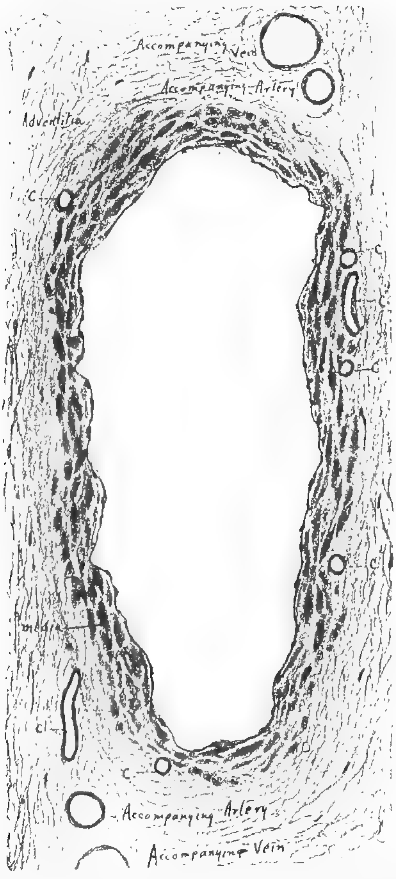

FIG. 316.—SECTION OF MODERATE-SIZED LYMPHATIC. (Evans.)
c, capillary vessels distributed to the muscular coat (tunica media).

have a clear, perfectly transparent appearance and a very thin wall, the latter is formed, first, by a lining of pavement-epithelium cells (lymphatic

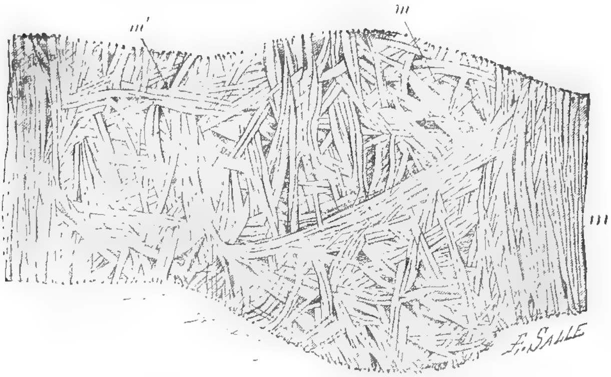

FIG. 317.—SUPRAVALVULAR DILATATION OF A LYMPHATIC OF THE MESENTERY OF A CAT; SILVER NITRATE PREPARATION. (Ranvier.)

m, circular muscle-fibres; *m'*, *m'*, irregular arrangement of muscle at the dilatation.

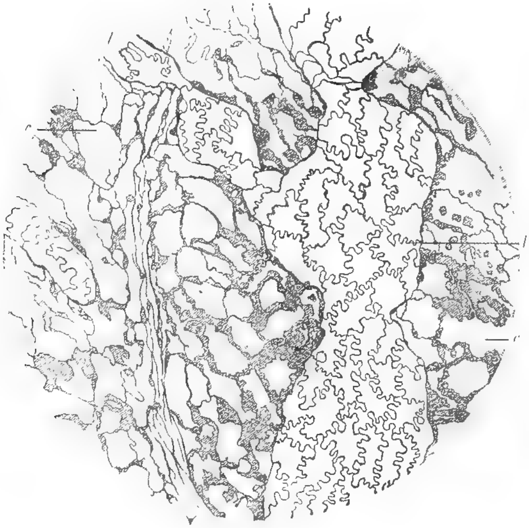

FIG. 318.—A SMALL PART OF THE LYMPHATIC PLEXUS OF THE PLEURAL LAYER OF THE DIAPHRAGM. Magnified 110 diameters. (Ranvier.)

l, lymphatics with characteristic epithelium; *c*, cell-spaces of the connective tissue here and there abutting against the lymphatic.

endothelium), which are elongated in the direction of the axis of the vessel; and, secondly, by a layer of circularly and obliquely disposed muscular fibres (fig. 317). In the smallest vessels (so-called *lymph-capillaries*, which are generally considerably larger than the blood-capillaries), there is nothing but the epithelium remaining, and the cells of this are frequently not more elongated in one direction than in another, but have a characteristic wavy outline (fig. 318).

The lymphatics receive numerous nerve-fibres, which are non-medullated, and which end in a ramification of the finest fibrils, which are distributed to the coats of the vessels (fig. 319).

Lymphatics begin either in the form of *plexuses*, as in serous membranes (fig. 320), or of *lacunar interstices*, as in some of the viscera: transitions occur between the two.

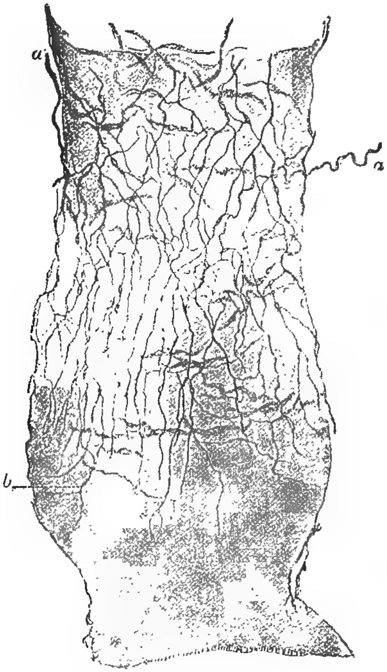

FIG. 319.—NERVES OF A LYMPHATIC VESSEL, SHOWN BY METHYLENE BLUE. (Dogiel.)

a, *a*, non-medullated fibres passing to the vessel; *b*, part of their terminal ramification.

In order to show their structure, it is usual to stain a tissue with nitrate of silver; for exhibiting their distribution they may be injected by sticking the nozzle of a very fine injecting cannula into any tissue which contains them, and forcing coloured fluid under gentle pressure into the interstices of the tissue.

In silver preparations it may be observed that the lymphatics always appear in the form of clear channels in the stained ground-substance of the connective tissue, and that their walls are in close connexion with the cells and cell-spaces of that tissue (fig. 320). But except in the case of the serous membranes, no open communication is observable between the lymphatic vessels and the interstices of the connective tissue, although from the readiness with which they can be injected from the latter there must be a ready means of passage of the interstitial lymph into the commencing lymphatics.

Development.- The lymphatic vessels were described by Klein, and more recently by Retterer, as being developed from hollowed-out cells in the same manner as the blood vessels, and by Gulland as becoming formed at the periphery as clefts in the connective tissue, which later form a connexion with the venous system. But the investigations of Ranvier, recently confirmed by Miss Sabin, Lewis, and others, have shown that the lymphatic trunks grow out at certain places from the venous system, and gradually spread from these spots to all parts of the embryo.

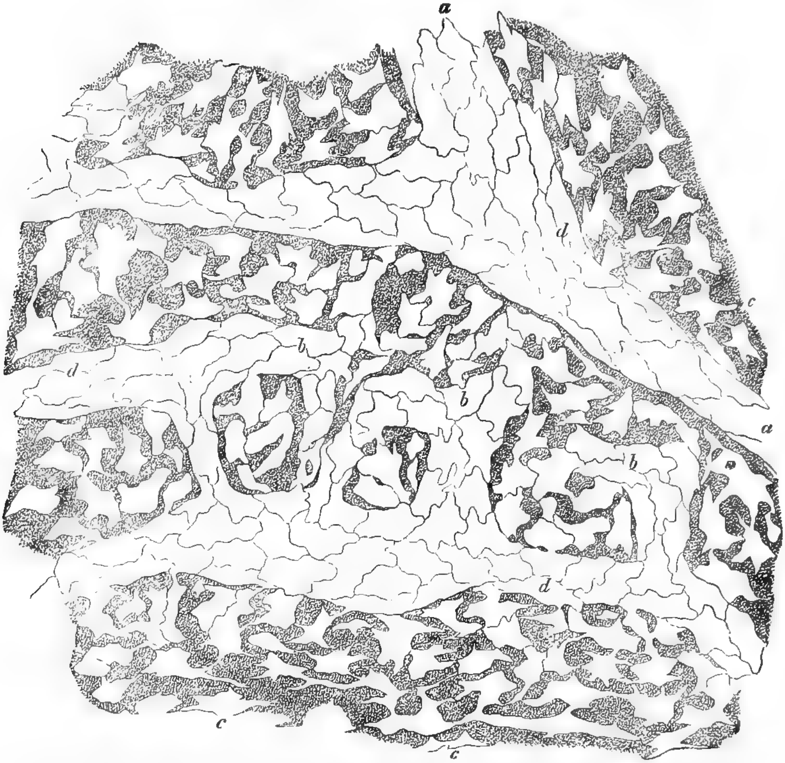

FIG. 320.—ORIGIN OF LYMPH-VESSELS IN CONNECTIVE TISSUE, SHOWN BY THE NITRATE OF SILVER METHOD. (V. Recklinghausen.)
a, lymphatic vessel passing away from the plexus of origin *d*; *b*, rootlets of the plexus, connected with cells of the surrounding connective tissue (seen as white cell-spaces in the brown ground-substance).

SEROUS MEMBRANES.

The **serous membranes**, which may be conveniently studied in connexion with the lymphatic system, are delicate membranes of connective tissue which surround and line the internal cavities of the body, and are reflected over many of the thoracic and abdominal viscera; in passing to these they

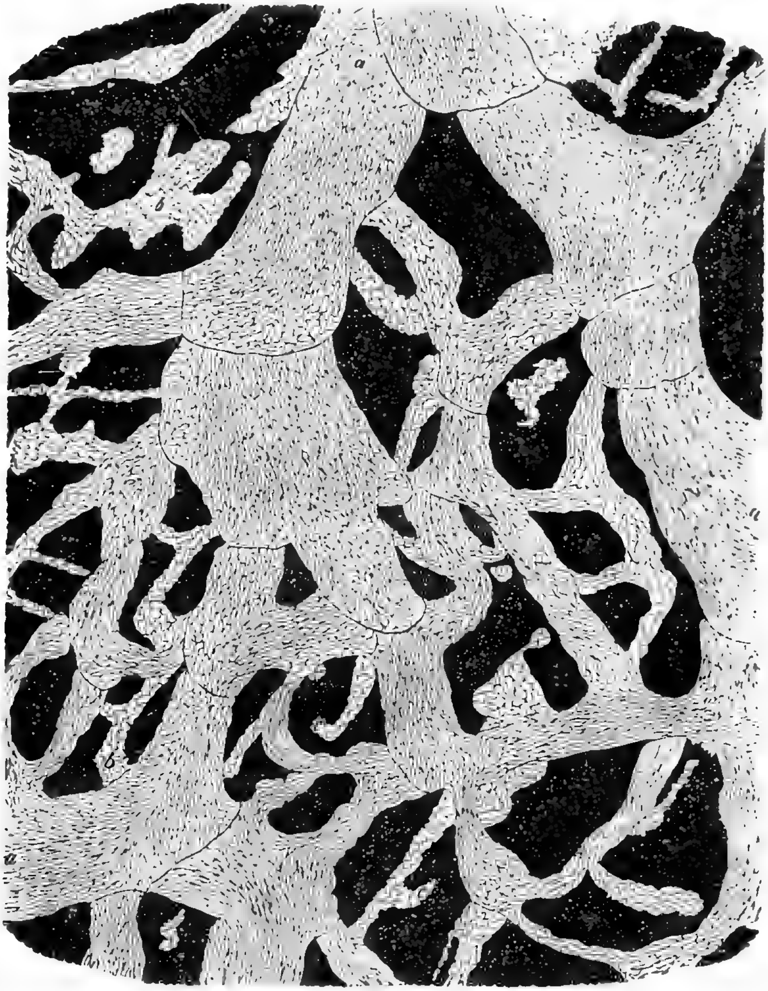

FIG. 321.—LYMPHATIC PLEXUS OF CENTRAL TENDON OF DIAPHRAGM OF RABBIT, PLEURAL SIDE. (Klein.)

a, larger vessels with lanceolate cells and numerous valves; *b*, *c*, lymph-capillaries with wavy-bordered cells. The cell-spaces of the connective tissue are not represented in this figure.

form folds (such as the mesentery), within which blood-vessels, lymphatics, and nerves are conducted to the viscera.

The inner surface is lined by a continuous layer of *pavement-epithelium* (*endothelium*) (fig. 322), which is very distinct in nitrate of silver preparations. This endothelium has a special structure in the form of a vertically striated free border (see p. 67). The cells are connected by intercellular bridges (fig. 323). In some places there are apertures in the epithelium which lead directly into subjacent lymphatic vessels. These apertures are called *stomata*, and are sometimes surrounded by special cells (fig. 324). They are numerous upon the peritoneal surface of the diaphragm, but are present in most serous membranes. They are nowhere better studied or more easily seen than in the peritoneal membrane at the back of the abdominal cavity in the frog. This membrane lies between and at the sides of the kidneys, and serves to separate the peritoneal cavity from the large lymph-space just behind it. If the membrane is prepared by the nitrate of silver method, both the stomata and the cells which bound them are shown on both sides of the membrane.

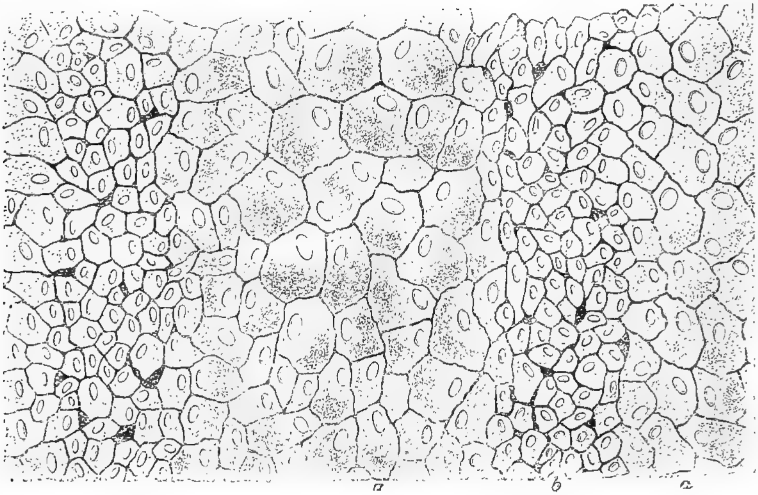

FIG. 322.—SEROUS ENDOTHELIUM FROM PERITONEAL SURFACE OF DIAPHRAGM. NITRATE OF SILVER PREPARATION. (Klein.)

a, layer; *b*, smaller cells. Between the latter are seen small irregular spaces (pseudo-stomata).

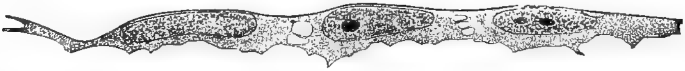

FIG. 323.—ENDOTHELIUM-CELLS OF SEROUS MEMBRANE SEEN IN PROFILE VIEW, SHOWING PROTOPLASMIC BRIDGES STRETCHING ACROSS THE INTERCELLULAR SPACES. (M. Heidenhain.)

The pavement-epithelium of the serous membrane rests upon a homogeneous basement-membrane, which is especially well marked in the serous membranes of man. The rest of the thickness of the membrane is composed of connective tissue, with a network of fine elastic fibres near the inner surface (fig. 325).

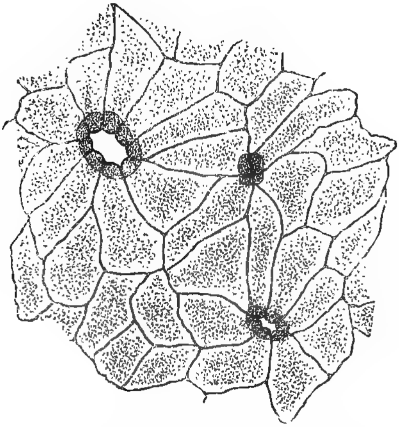

FIG. 324.—ENDOTHELIUM FROM THE POSTERIOR PART OF THE FROG'S PERITONEUM, SHOWING THREE STOMATA LEADING INTO THE CISTERNA LYMPHATIC MAGNA. (v. Ebner, after Ludwig and Schweigger-Seidel.)

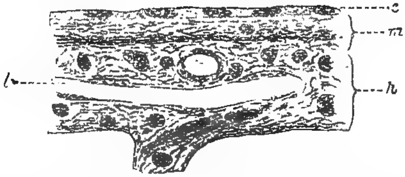

FIG. 325.—SECTION OF PLEURA : OX. (Favaro.) Magnified 270 diameters.

e, endothelium ; *m*, substance of membrane with numerous elastic fibres ; *h*, sub-pleural layer ; *l*, lymph-vessel.

Development.—The serous cavities are originally formed in the embryo as a cleft in the mesoderm (pleuro-peritoneal split, cœlom) which becomes lined with endothelium, and, later, becomes separated into peritoneum, pleura, and pericardium. Outside the endothelium the cœlomic wall eventually becomes differentiated into the tissues of the serous membrane.

LESSON XXII.

LYMPH-GLANDS, SPLEEN, TONSILS, THYMUS.

1. SECTIONS of a lymph-gland which has been hardened in formol (or potassium bichromate, or chromic acid or picric acid followed by alcohol) stained in bulk, and embedded in paraffin. Or the sections may be stained with hæmatoxylin and eosin. Notice (1) the fibrous and muscular capsule, with trabeculæ extending inwards from it through the cortex and anastomosing with one another in the medulla, (2) the dense lymphoid tissue (adenoid tissue of some authors) forming large masses in the cortex (cortical nodules) and rounded cords in the medulla (medullary cords). Notice also the clearer channel or lymph-sinus which everywhere intervenes between the fibrous tissue and the lymphoid tissue. Observe the fine fibres and branched cells which bridge across this channel.

Make a general sketch under a low power of a portion of the cortex together with the adjoining part of the medulla, and under a high power drawings of small portions of cortex and medulla.

The retiform tissue of the lymph-glands has already been studied (pp. 88 to 90).

2. Sections of a hæmal lymph-gland. These may be readily found in the neck of the ox, in the neighbourhood of the large blood-vessels. Stain with eosin and hæmatoxylin or with eosin and methylene blue. Notice that the channels around the lymphoid nodules (or some of them) contain blood instead of lymph.

3. Sections of the spleen hardened in Müller's fluid or formol and stained with hæmatoxylin and eosin. Notice the trabeculæ extending into the substance of the organ from the capsule. Notice also that the glandular substance is of two kinds, (1) lymphoid tissue accumulated around the small arteries and here and there massed to form *lymphoid nodules*—the Malpighian corpuscles—and (2) a tissue—the red pulp—consisting of a reticulum of fibrils and branching cells: this tissue contains blood in its interstices.

Sketch part of a section under a low power and a small portion of the pulp under a high power.

4. In sections of tonsil prepared similarly to those of the lymph-gland, notice the large amount of lymphoid tissue, partly collected into nodules. Observe also that the stratified epithelium, which covers the mucous membrane here as elsewhere in the mouth, is infiltrated with lymph-corpuscles. The tonsil is beset with pit-like recesses, with mucus-secreting glands opening into the pits.

5. Lymphoid nodules of mucous membranes. In other mucous membranes besides that of the back of the mouth and pharynx, collections of lymphoid tissue occur which resemble those of the tonsils; such nodules form the solitary glands of the stomach and intestines and the agminated glands of the small intestine, and are also found in the trachea and bronchial tubes and in the œsophagus. They will be studied later in sections of those parts.

6. Sections of the thymus gland of an infant or young animal. Notice that the masses of lymphoid (?) tissue which form the lobules of the gland are separated by septa of connective tissue, and that the lobules show a distinction into two parts, cortical and medullary. There are no lymph-paths within the lobules. Observe the differences of structure of the cortex and medulla, and especially notice the concentric corpuscles in the medullary part.

Make a sketch of one of the lobules under a low power and of a small part of the medulla under a high power, including one or two concentric corpuscles. Measure the latter.

LYMPH-GLANDS.

Structure of a lymph-gland.—A lymph-gland (lymphatic gland) is composed of a framework of fibrous and plain muscular tissue, which encloses and supports the proper glandular substance, but is everywhere separated from it by a sinus-like channel, bridged across by cells and fibres, which is known as the *lymph-channel.* The *framework* consists of an envelope or *capsule* (fig. 326, *c*), and of *trabeculæ* (*tr*), which pass at intervals inwards from the capsule, and after traversing the cortex of the gland, divide and reunite with one another to form a network of fibrous bands. At one part of the gland there is usually a depression (*hilus*), and at the bottom of this the medulla comes to the surface and its fibrous bands are directly continuous with the capsule.

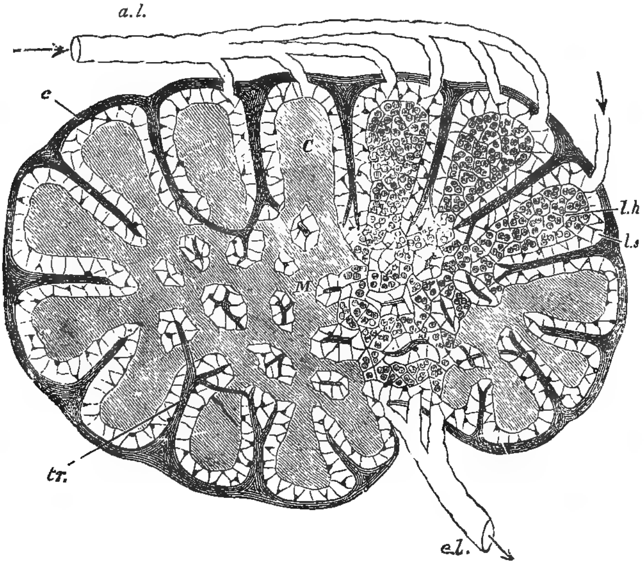

FIG. 326.—DIAGRAMMATIC SECTION OF LYMPH-GLAND. (Sharpey.)

a.l, afferent, *e.l.*, efferent lymphatics; *C*, cortical substance; *M*, reticulating cords of medullary substance; *l.h.*, lymphoid tissue; *l.s.*, lymph-sinus; *c*, capsule sending trabeculæ, *tr*, into the substance of the gland.

The proper *glandular substance* (*l.h.*) is composed of lymphoid tissue, *i.e.* a fine reticulum with the meshes thickly occupied by lymph-corpuscles. It occupies all the interstices of the gland, forming comparatively large rounded masses in the cortex (lymphoid nodules, *C*), which may be two or three deep, and smaller reticulating cord-like masses (lymphoid cords, *M*) in the medulla.

The lymph-channel is bridged across by fibres derived from the capsule and trabeculæ, which pass to the lymphoid tissue and merge into its reticulum (figs. 327, 328). But the fibres are often largely concealed by branching cells, which were indeed at one time thought to constitute the reticulum. In some animals (*e.g.* ox) these cells contain pigment, giving the medulla a dark colour. Occasionally they contain disintegrating erythrocytes or reddish granules derived from the disintegration: and they are also apt to take in foreign particles which have become absorbed into the lymph and thus conveyed to the gland. Thus it is common for the lymph-glands at the root of the lung to contain carbon particles which have been inhaled in the form of soot.

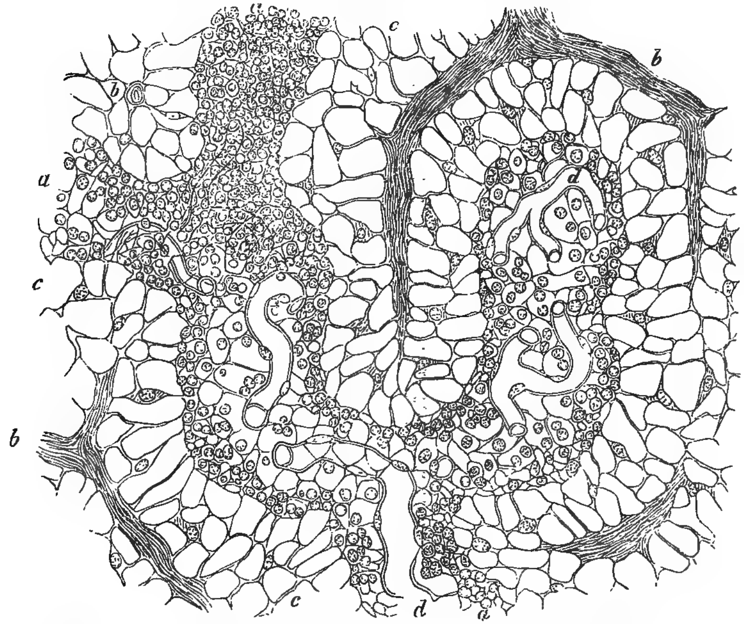

FIG. 327.—SECTION OF THE MEDULLARY SUBSTANCE OF A LYMPH-GLAND. Magnified 300 diameters. (Recklinghausen.)

a, a, a, lymphoid cords; *c,* lymph-sinus; *b, b,* trabeculæ; *d, d,* capillary blood-vessels.

The phagocytic function of the branched cells of the medulla is shared by certain large cells which are sometimes found lying loose in the lymph-channel and which resemble the large phagocytes found in the pulp of the spleen.

Giant cells with lobed nuclei are also occasionally seen in the lymph-channels.

The branched cells which cover the reticulum are continued over the trabeculæ, and at the entrance and exit of the lymphatics they are continuous with the endothelium-cells of these vessels. They represent therefore a lymphatic endothelium bounding the lymph spaces, but like the corresponding endothelium of the small veins of the spleen they have become branched and form part of the supporting reticulum of the organ.

Afferent lymph-vessels (fig. 326, *a.l.*) enter the lymph-sinuses of the cortex after ramifying in the capsule, and the lymph is conveyed slowly along the channels of the cortical and medullary part towards the hilus, taking up lymph-corpuscles in its passage. At the hilus it is gathered up by an efferent vessel or vessels (*e.l.*) taking origin in the lymph-sinuses of the medulla.

The efferent lymphatics always contain many more lymph-corpuscles than those which enter the gland, for lymph-corpuscles are constantly being formed by karyokinetic division of the pre-existing cells in the glandular substance, especially in the centre of each cortical nodule (*germ-centre* of Flemming); they gradually find their way through the close reticulum of the lymphoid tissue into the lymph-channels.

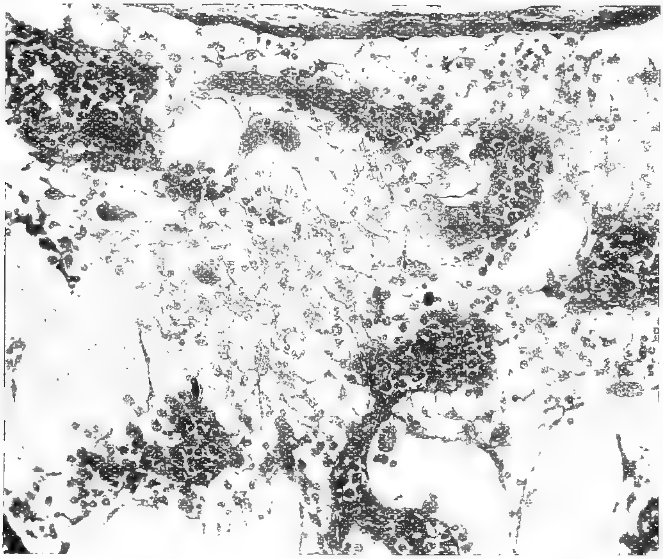

FIG. 328.—SECTION OF MEDULLA OF LYMPH-GLAND OF DOG SHOWING RETICULAR TISSUE IN THE LYMPH-CHANNEL EXTENDING BETWEEN THE LYMPHOID CORDS AND TRABECULÆ. Magnified 200 diameters. (From a preparation by Dr M. Heidenhain.)

The leucocytes of the germ-centres frequently show, in sections, peculiar darkly coloured bodies—the *stainable bodies* of Flemming—the origin of which has not been determined.

An artery passes into each gland at the hilus; its branches are conveyed at first along the fibrous cords, but soon become surrounded by the lymphoid cords, where they break up into capillaries (fig. 327, *d*). The blood is returned by small veins, which are conducted along the fibrous trabeculæ, joining to form large vessels which eventually emerge at the hilus.

In some lymph-glands the fibrous trabeculæ are very slightly developed so that the gland seems in section to be a mass of almost uniform lymphoid tissue, pervaded by lymph-channels and with clearer rounded nodules (germ-centres) scattered about, especially in the cortex (fig. 329). This condition obtains with most of the lymph-glands of man and some other animals. In certain other animals, such as the cat, dog, and ox, the trabeculæ are well developed, and contain much muscular tissue, and the lymph-channels are correspondingly well marked off.

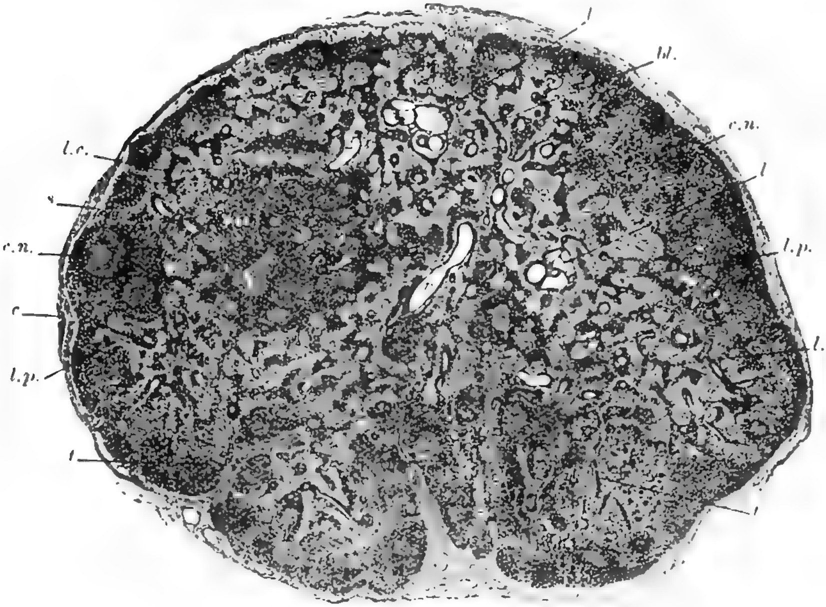

FIG. 329.—SECTION OF A LYMPH-GLAND FROM THE NECK OF AN EIGHT YEAR OLD CHILD. (v. Ebner.) 13.

c, capsule; *c.n.*, cortical nodules, some with germ-centres; *l.c.*, lymphoid cords of medulla (dark); *l.p.*, lymph-path (light); *s*, cortical sinus; *t*, trabeculæ; *v*, vein; *l*, efferent lymph-vessels, accompanying and partly surrounding blood-vessels, *bl*.

Nerve fibres pass to lymph-glands: they appear to be distributed chiefly as non-medullated fibres to the plain muscular tissue of the blood-vessels and trabeculæ.

Hæmal lymph-glands.—In many animals a certain number of lymph-glands are observable which have a red colour. Some of these on section show that what corresponds to the peripheral lymph-channel in ordinary lymph-glands is in them occupied by blood. Others have the greater part of the interior occupied by large sinuses filled with blood; while other parts show the ordinary structure of a lymph-gland. The names *hæmal glands* and *hæmal lymph-glands* (Robertson) have been given respectively to these structures. The blood passes into the sinuses from arterial capillaries, which

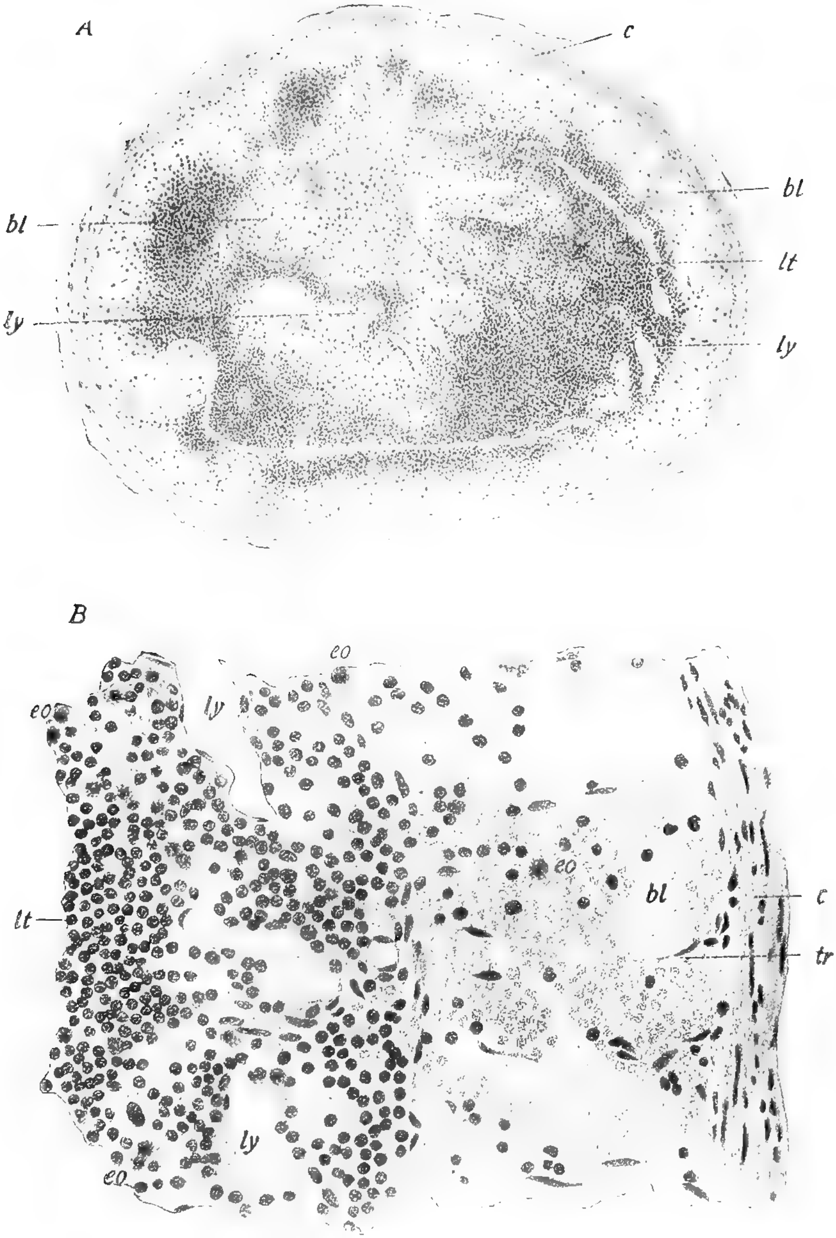

FIG. 330.—SECTION OF A HÆMAL LYMPH-GLAND. *A*, magnified 50 diameters; *B*, magnified 350 diameters.

c, capsule with plain muscle-fibres; *tr*, fine trabeculæ passing in from capsule; *bl*, blood-sinuses full of blood-corpuscles; other red corpuscles are seen in the interstices of the lymphoid tissue, *lt*; *ly*, lymph-sinuses; *eo*, eosinophil-cells amongst the lymphocytes of the lymphoid tissue.

appear, as in the spleen, to open into the tissue interstices, from which at other parts small veins arise in like manner. Like the spleen these hæmal glands show numerous large phagocytes which contain red blood-corpuscles in various stages of transformation into pigment.

Some hæmal glands are said to have no lymph-channels, but to be purely blood-glands: in that case they may be considered to represent accessory spleens.

Ordinary lymph-glands are confined to mammals, but Vincent and Harrison have found hæmal lymph-glands in birds.

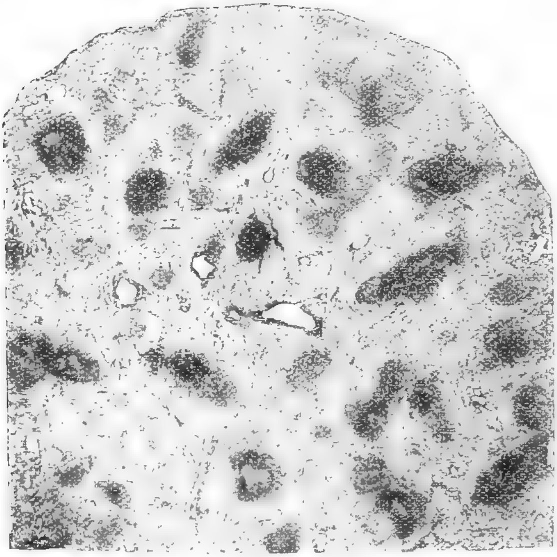

Fig. 331.—Section of spleen, somewhat magnified. (G. Mann.)

The section was stained, and the Malpighian corpuscles therefore appear darker than the pulp. The venous sinuses show as clear spaces. The larger veins are contained in the trabeculæ.

THE SPLEEN.

The **spleen** is the largest of the so-called ductless glands. It appears to be functionally connected with the blood, white blood-corpuscles being formed and coloured blood-corpuscles being submitted to destruction within it.

Like the lymph-glands, the spleen is invested with a fibrous and muscular *capsule* (fig. 332), which is, however, stronger and has far more plain muscular tissue; outside the capsule is a covering derived from the peritoneum. The capsule sends bands of trabeculæ into the organ, and these join with a network of similar trabeculæ which pass into the gland at the hilus along with the blood-vessels. In the interstices of the framework thus constituted lies a soft pulpy substance containing a large amount of blood, and therefore of a deep red colour, dotted within which are here and there to be seen small round bodies, whiter than the pulp in the fresh organ but darker in stained sections, the *Malpighian corpuscles* of the spleen. These are composed of lymphoid tissue which is gathered up into masses which envelop the smaller arteries, whilst the red pulp which everywhere surrounds them and which forms the bulk of the organ is composed (Carlier) of a close network of connective-tissue fibrils (fig. 333), partly covered by flattened and branched cells (figs. 334, 335). Passing into the pulp and communicating with its interstices are capillary blood-vessels which are connected with the terminations of the arteries; whilst in other parts venous channels—characterised in the human spleen by an encirclement of reticulum-fibres (fig. 335), and by the presence of a layer of highly characteristic, comparatively thick and prominent endothelium-cells—course through the pulp and bring the blood which has passed into its interstices from the arterial capillaries towards the larger veins of the organ, which run in the trabeculæ and are by them conducted to the hilus. The arteries, which are also at first conducted from the hilus along the

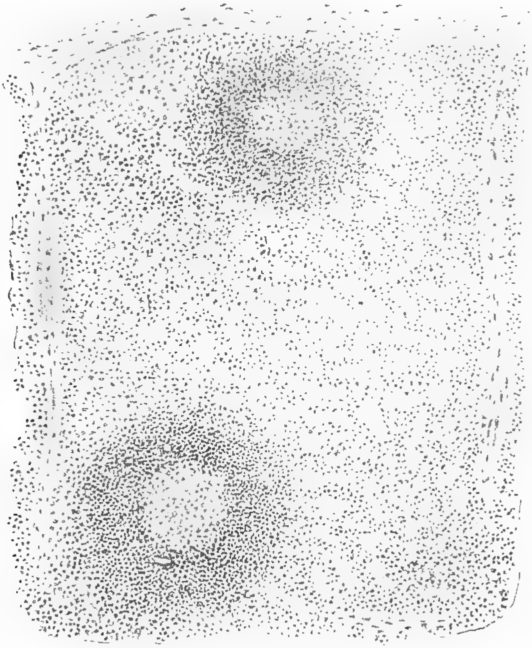

FIG. 332.—VERTICAL SECTION OF A PORTION OF THE MONKEY'S SPLEEN, AS SEEN WITH A LOW POWER.

Part of the capsule, two trabeculæ and two Malpighian corpuscles are represented.

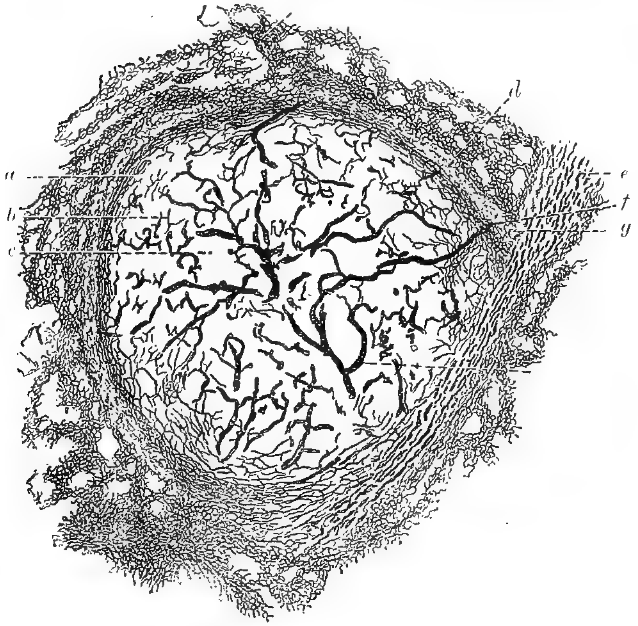

FIG. 333.—RETICULUM OF SPLEEN, GOLGI METHOD. Low power. (Oppel.)

a Malpighian corpuscle; *b*, part of its reticulum; *c*, condensed reticulum at its margin; *d*, more open tissue next to this; *e*, wall of arteriole; *f*, capillaries of Malpighian corpuscle; *g*, reticulum of arteriole expanding into that of the Malpighian corpuscle.

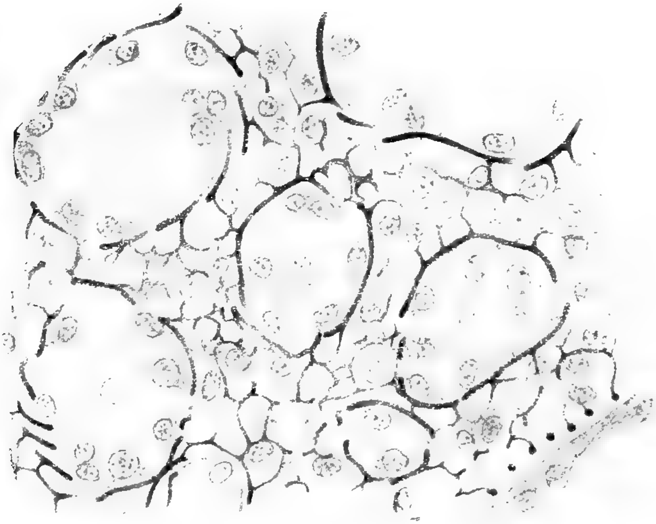

FIG. 334.—SMALL VEINS OF SPLEEN-PULP WITH RETICULAR TISSUE: HUMAN. High power. (Hoyer.)

The veins, which are invested by encircling fibres, show gaps in their walls whereby they communicate with the interstices of the pulp.

trabeculæ into the interior of the organ, presently leave the trabeculæ, and their external coat becomes gradually converted into a thick sheath of lymphoid tissue which invests them in the remainder of their course, and in places becomes swollen into the Malpighian corpuscles already mentioned.

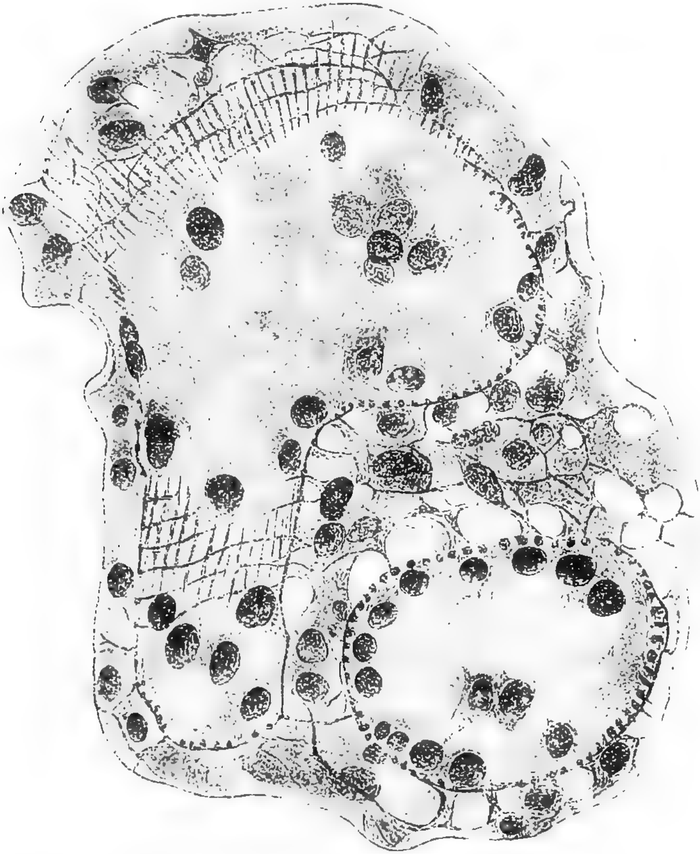

Fig. 335. Venous sinuses of spleen-pulp (monkey), showing the encircling fibres in their walls which are derived from cells of the reticulum and are attached to longitudinal fibres which belong to the endothelium of the sinuses. (S. Mollier.) High power.

The small arteries distribute a few capillaries to the Malpighian corpuscles, and then break up into pencils of capillary vessels which open into the interstices of the pulp.

The Malpighian corpuscles frequently but not always show a clearer central nodule or *germ-centre*, characterised by the presence of numerous karyokinetic figures; and the "stainable bodies" of Flemming, which have been noticed under lymph-glands, are also seen in them.

The special cellular elements of the spleen-pulp are of three kinds, viz., (1) large, amœboid phagocytic *splenic cells* (fig. 336), (2) *giant cells* (fig. 337), (3) branched *reticulum-cells* which assist in forming the sponge-work (fig. 336). In addition to these the pulp contains all the corpuscular elements of blood. The phagocytic cells are frequently found to contain coloured blood-corpuscles in their interior in various stages of transformation into pigment. These cells occur both in the interstices of the pulp and in the venous sinuses and veins, where they are often full of erythrocytes (fig. 336). The giant cells are most frequent in young animals. The branched cells of the sponge-work are probably of the same nature as the endothelium-cells of the terminal capillaries and veins of the pulp. They are connected by branches with one another and with the endothelial-cells of the vessels. The phagocytic spleen-cells are perhaps budded off from them.

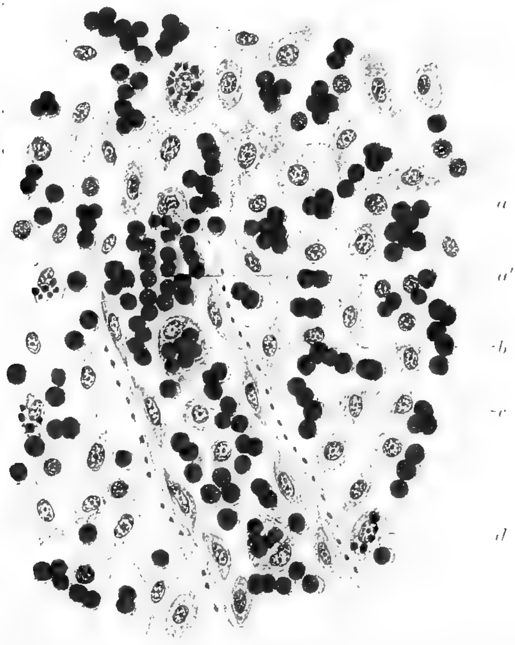

FIG. 336.—THIN SECTION OF SPLEEN-PULP OF CHILD, HIGHLY MAGNIFIED, SHOWING THE APPARENT MODE OF ORIGIN OF A SMALL VEIN IN THE INTERSTICES OF THE PULP. Magnified 400 diameters.

a, blood in pulp; *a′*, blood in vein; *b*, phagocyte in vein; *c*, branched cell of pulp; *d*, phagocytic splenic cell.

Nucleated coloured corpuscles are found in the embryo, and occasionally, after birth, in the spleen-pulp. The blood of the splenic vein is very rich in leucocytes.

The lymphatics of the spleen run partly in the trabeculæ and capsule, and partly in the lymphoid tissue ensheathing the arteries. They join to form larger vessels which emerge together at the hilus. There are no lymphatics in the spleen-pulp itself.

The nerves, which are numerous and mostly non-medullated, are distributed to the muscular tissue of the arteries and to that in the capsule and trabeculæ.

Mall finds the distribution of the trabeculæ and of the blood-vessels within the spleen to indicate a differentiation of the pulp into divisions (spleen lobules) each of which has its own arteriole and venule, and in which the pulp is arranged in columns or cords surrounded by venous spaces. It must, however, be understood that there is nothing of the nature of partitions separating such lobules; to all appearance the pulp is in continuity throughout the organ.

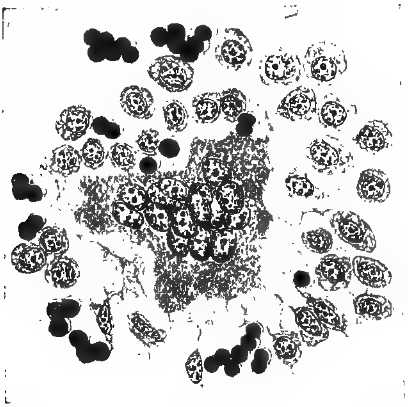

FIG. 337.—A GIANT CELL FROM THE SPLEEN OF A KITTEN. Magnified 400 diameters.

THE TONSILS AND OTHER LYMPHOID STRUCTURES.

The **tonsils** are two masses of lymphoid tissue placed one on each side of the pharynx, into which they project. They are covered on the free surface with the stratified epithelium of the mucous membrane, and this surface is pitted with apertures which lead into recesses or crypts in the substance of the organ (fig. 338). These recesses are all lined by a prolongation of the stratified epithelium of the surface and into them the ducts of numerous small mucous glands open. The tonsils are composed of lymphoid tissue, which, besides being diffused over the whole organ, is at intervals aggregated into nodules, in which the lymph-cells are more closely arranged than elsewhere. In the clear centre (*germ-centre*) of these nodules active multiplication of the lymph-cells occurs and is, in fact, the cause of the formation of such nodules; as in the other organs (spleen, lymph-glands) in which lymphoid tissue occurs. Even the epithelium which covers the tonsils is infiltrated with lymph corpuscles (figs. 338, 339), many of which wander out on to the free surface, and become mingled with the saliva as salivary corpuscles.

The lymphoid tissue of the tonsils has numerous blood-vessels; it also contains lymphatic vessels.

The mucous membrane of the neighbouring part of the pharynx, that of the back of the tongue, and that of the upper part of the pharynx, near the orifices of the Eustachian tubes and behind the posterior nares, shows crypts and masses of lymphoid or adenoid tissue similar in structure to those of the tonsils.

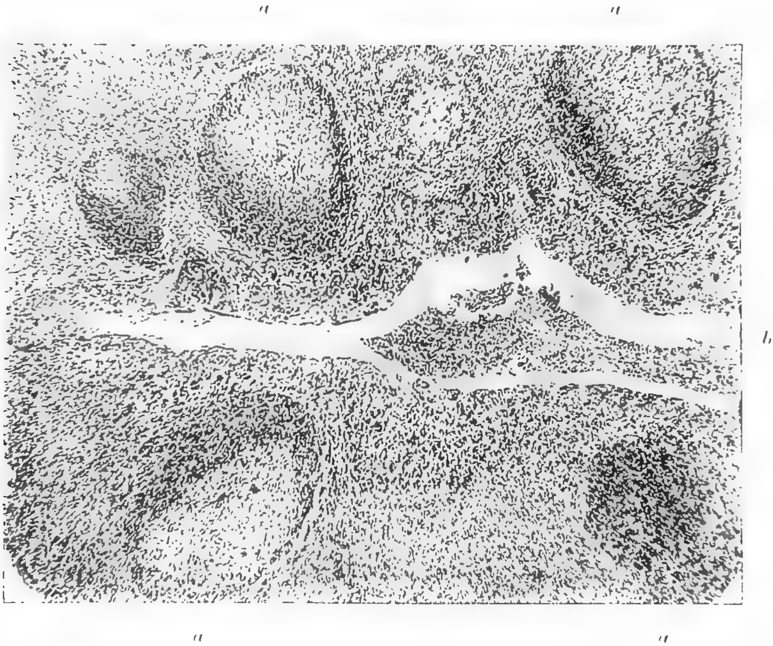

FIG. 338.—SECTION OF TONSIL: HUMAN. Magnified 50 diameters. (Photographed from a preparation by Prof. M. Heidenhain.)

a, *a*, nodules or germ-centres; *b*, a recess lined by stratified epithelium which is permeated by leucocytes. Opposite *b*, a mass of leucocytes which have escaped into the cavity of the recess.

Lymphoid tissue occurs in many other parts of the body in addition to the lymph-glands and tonsils, although it may not, as in these structures, constitute the bulk of the organ. Thus it is found in many mucous membranes, such as those of the alimentary and the respiratory tracts, both in a diffuse form and also collected into nodular masses which are like the cortical nodules of a lymph-gland, and may, like these, be partially surrounded by a lymph-sinus. In the intestine such nodules constitute the so-called *solitary glands* and *Peyer's patches*. In the vermiform appendix the mucous membrane is thickly beset with such nodules. The lymphatics form plexuses of sinus-like vessels which to a large extent enclose the nodules (fig. 340). In the spleen, as we have seen, a large amount of lymphoid tissue is found ensheathing the smaller arteries, expanded here and there into the nodular masses known as Malpighian corpuscles. Lymphoid tissue also occurs in considerable amount in the serous membranes, especially in young animals; in the adult it is here largely replaced by adipose tissue.

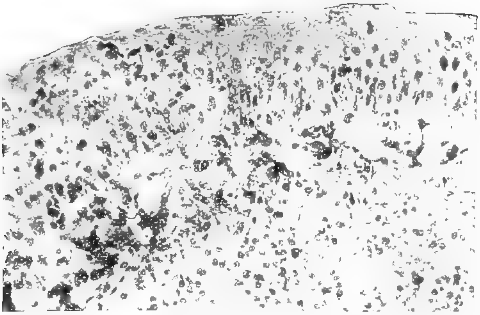

FIG. 339.—PART OF A SECTION OF RABBIT'S TONSIL SHOWING INFILTRATION OF THE EPITHELIUM BY LEUCOCYTES. Photograph. Moderately magnified.

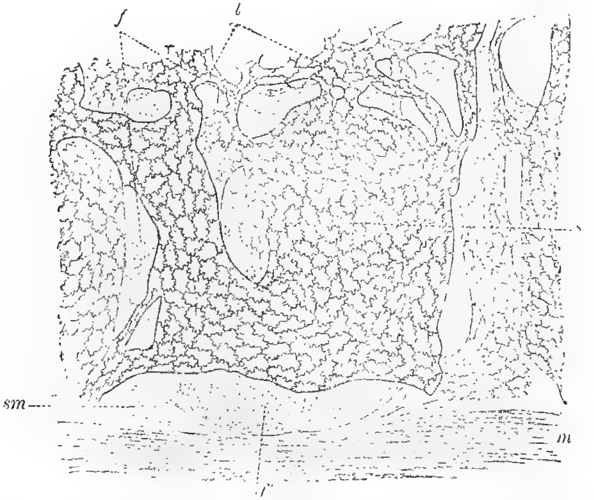

FIG. 340.—LYMPHATICS OF A PEYER'S PATCH, INJECTED WITH SILVER NITRATE. (Kölliker.) Magnified 85 diameters.

f, a lymphoid nodule or follicle; *f'*, its base, resting upon the muscular coat, *m*; *sm*, submucosa; *l*, lymph-vessels; *s*, sinus-like enlargement of lymph-vessel surrounding follicle.

Development of lymphoid tissue.—Lymph-glands are developed in connexion with plexuses of lymph-vessels, an accumulation of retiform tissue and lymph-cells taking place either external to and around the lymphatics (*perilymphatic forma-*

tion); or some of the lymphatics are dilated into a sinus or sinuses and the formation of the lymphoid tissue occurs within it (*endolymphatic formation*) (fig. 341, A and B). When there is a development of lymphoid tissue outside the lymphatic vessels this may form a considerable accumulation before the formation of lymph-paths appears within the tissue. Blood-vessels are early developed amongst the lymphatic plexuses, and by these, according to Gulland, the first lymph-corpuscles of the lymphoid tissue are brought to the gland.

The marginal sinus is produced by the fusion of a number of lymph-vessels which surround the commencing accumulation of lymphoid tissue, while in the situation of the future hilus other lymph-vessels grow into the glandular substance and form channels which subdivide it up into cords and nodules (Kling). The branched cells of the lymph-path are derived from the lymphatic endothelium.

The axillary glands were found by Stiles to increase in number and size during lactation, diminishing again after lactation has ceased. In the developing tonsils Gulland occasionally found nests of epithelial cells detached from the surface epithelium, somewhat like those found permanently in the thymus.

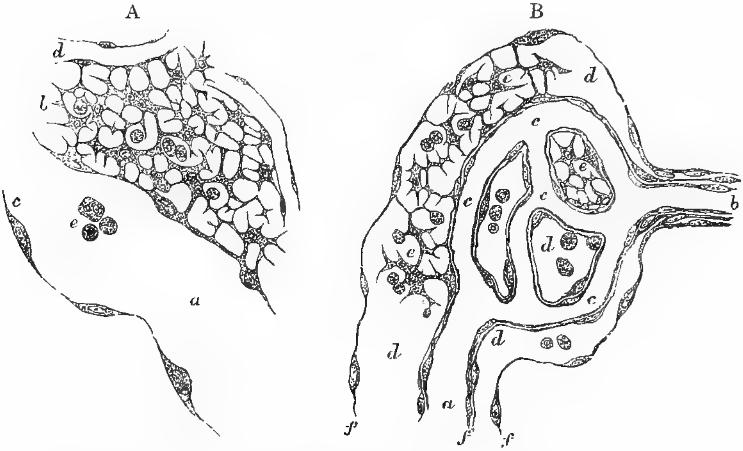

FIG. 341.—DEVELOPING LYMPHOID NODULES FROM THE GUINEA-PIG'S OMENTUM. (Klein.)

A, perilymphatic nodule; *a*, lymphatic; *c*, its endothelium; *e*, lymph-corpuscles; *b*, accumulation of lymphoid tissue on one side of it; *d*, blood-capillaries within this.

B, endolymphatic nodule consisting of an enlarged lymphatic vessel, *d*, within which is a capillary network, *c*, *c*, an artery, *b*, and a vein, *a*; *e*, lymphoid tissue within the lymphatic, its branched cells being joined to and derived from the lymphatic endothelium, *f*.

THYMUS.

The **thymus gland** is an organ which normally in man is found in a fully developed condition only in the fœtus and infant. It is composed of a number of lobules (fig. 342) varying in size, separated from one another by septa of connective tissue, along which the blood-vessels pass to and from the lobules. Each lobule shows plainly, when examined with a low power, a distinction into an outer cortical and an inner medullary portion. The cortical part of the lobule is imperfectly divided into nodules by trabeculæ of connective tissue. It is superficially similar in structure to the lymphoid tissue of the lymph-glands and tonsils, with which it also agrees in exhibiting numerous indications of indirect cell division, but without definite germ-centres. Besides lymph-corpuscles it contains a number of peculiar granular cells. The medulla is more open in its texture,

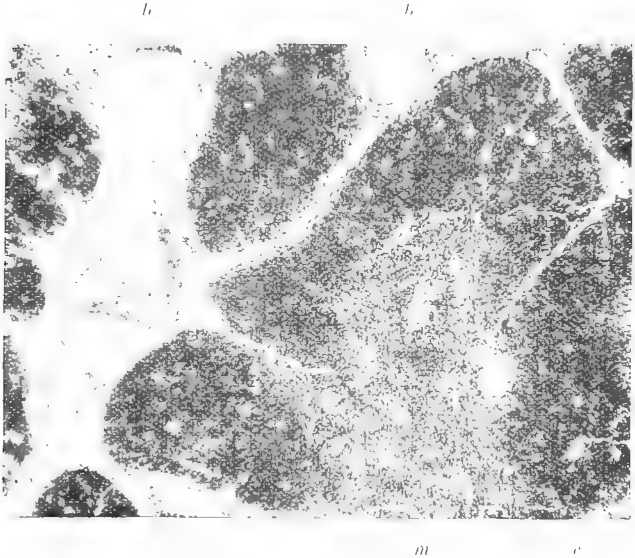

FIG. 342.—SECTION OF PART OF LOBULE OF THYMUS OF CHILD. Photograph Magnified 60 diameters.

c, cortex; *m*, medulla; *b*, *b*, blood-vessels in connective-tissue trabeculæ.

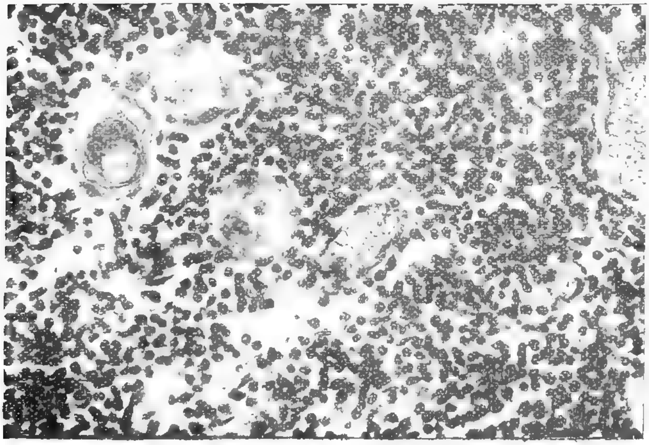

FIG. 343.—MEDULLA OF THYMUS OF A CHILD. Photograph. Magnified 300 diameters.

The small darkly stained cells are lymphocytes. The section includes two concentric corpuscles and some blood-vessels full of corpuscles.

and its reticulum is formed by large, transparent, branched cells (fig. 344), which are sometimes massed together and then resemble epithelium-cells. The medulla contains fewer lymph-corpuscles than the cortex and has a clearer aspect. Connective-tissue fibres are not wholly absent from it. Within the medulla, but not in the cortex, are found peculiar concentrically striated bodies (the *concentric corpuscles of Hassal*, figs. 343, 345), which are "nests" of flattened epithelial cells arranged concentrically around one or more central cells, which have often undergone a degenerative process. Sometimes these corpuscles are compound, two or three being grouped together and similarly enclosed by flattened cells. They represent part of the remains of an epithelial tube, which forms the thymus rudiment of the early embryo and is derived from certain of the branchial clefts. According to the observations of Hammar the reticulum of the gland is also derived from this epithelium; Stöhr believed the apparent lymphoid cells of the gland to have a similar origin, but there are good reasons for thinking that this is not the case.

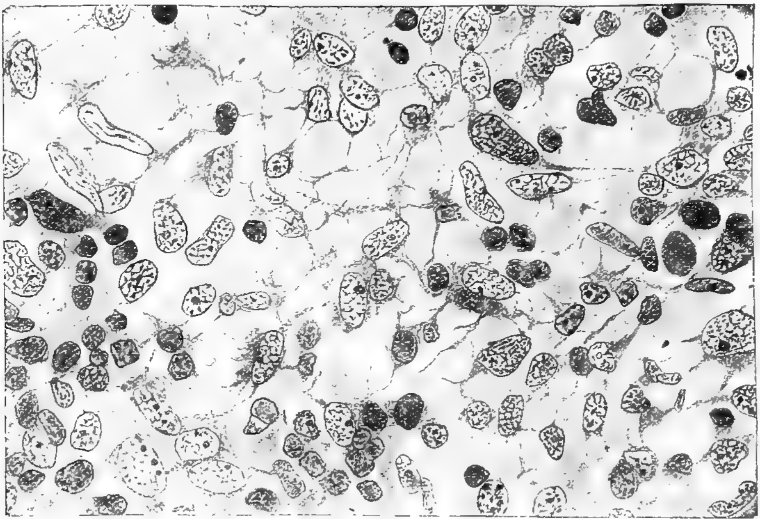

FIG. 344.—SECTION OF MEDULLA OF THYMUS, SHOWING BRANCHED CELLS FORMING A RETICULUM WITH A CERTAIN NUMBER OF LYMPHOID CELLS IN ITS MESHES. (Hammar.)

Nucleated red blood-corpuscles (erythroblasts), similar to those seen in red marrow, have also been described in the thymus (J. Schaffer), and occasionally cysts lined by ciliated epithelium are found (fig. 345, *c*). In some animals isolated striated muscular cells are seen in the medulla. Multinucleated giant cells have also been found in it (H. Watney).

The lobules, the cortex especially, are abundantly supplied with capillary blood-vessels. In man the arteries penetrate to the junction of cortex and medulla, and then give off most of their capillaries radiating outwardly into the cortical nodules, although some vessels pass inwards to supply the medulla. Veins pass away both from the surface of the lobules and to a less extent directly from the medulla. The mode of distribution of the lymphatics has not been definitely ascertained; none are seen within the lobules. Nevertheless, large lymphatic vessels, containing many lymphocytes, issue from the interstitial connective tissue of the organ, but in what way they are connected with the lobules has not been ascertained.

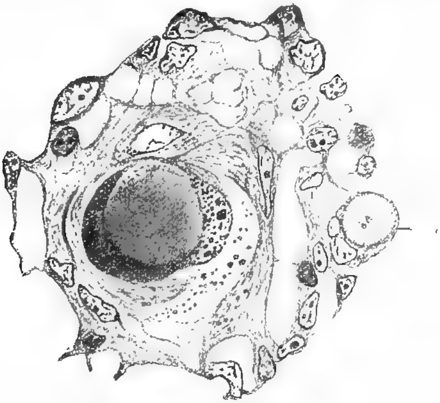

FIG. 345. A CONCENTRIC CORPUSCLE OF THYMUS WITH PART OF THE ADJOINING RETICULUM. (Hammar.)

c, a small ciliated cyst.

In the human subject the thymus gland undergoes after childhood a process of retrogression, its lobules ceasing to grow and becoming surrounded and concealed by a quantity of adipose tissue which develops in the interstitial connective tissue of the gland. Eventually the lobules atrophy, so that in advanced age very little of the gland remains. In exceptional cases this retrogressive or involution process does not occur. In these subjects there is usually also a more pronounced development of the lymphoid tissue of the body generally; the condition is denoted by the expression *status lymphaticus*.

LESSON XXIII.

SUPRARENAL CAPSULES, THYROID, PARATHYROIDS, PITUITARY, AND PINEAL.

1. SECTIONS across a suprarenal capsule hardened in 2 per cent. bichromate of potassium. In sections not otherwise stained, notice the deep brown coloration of the medulla (action of the chromic salt). Other sections may be stained with eosin and hæmatoxylin or by the iron-hæmatoxylin method. Notice the general arrangement and extent of the cortical and medullary parts of the organ, and make a general sketch under a low power. Afterwards sketch carefully under a high power a group of cells from each part of the organ.

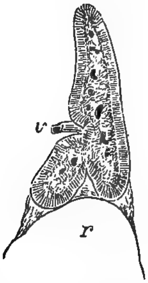

FIG. 346.—A VERTICAL SECTION OF THE SUPRARENAL BODY OF A FŒTUS, TWICE THE NATURAL SIZE, SHOWING THE DISTINCTION BETWEEN THE MEDULLARY AND CORTICAL SUBSTANCE. (A. Thomson.)

v, issuing vein; *r*, summit of kidney.

2. Sections of the thyroid body stained with eosin and hæmatoxylin. Notice the vesicles lined with cubical epithelium and filled with a "colloid" substance which becomes stained with hæmatoxylin. Sketch one or two vesicles. Measure several vesicles. The sections should include a parathyroid.

3. Sections (antero-posterior) through the pituitary body. Notice the (epithelial) anterior lobe separated by a cleft from the (nervous) posterior lobe. The anterior part of the posterior lobe is also covered by an epithelial layer, amongst the cells of which colloid matter may be seen. This also can be traced in the tissue of the posterior lobe as far as the infundibulum of the third ventricle.

4. Sections (antero-posterior) through the pineal gland. This should if possible be obtained from a brain hardened *in situ* by injection of the blood-vessels with 10 per cent. formol, after first washing out the contained blood with Ringer's solution.

THE SUPRARENAL CAPSULES.

The **suprarenal capsules (adrenals)** belong to the class of bodies known as ductless glands, but they are entirely different in structure and function from the spleen and lymphatic glands. A section through the fresh organ (fig. 346) shows a *cortex* which is striated vertically to the surface, and of a yellowish colour, and a *medulla* which is soft and highly vascular, and of a dark red colour. The whole organ is invested by a fibrous *capsule* which sends septa inwards through the cortical substance (fig. 347, *a*), subdividing this for the most part into columnar groups of cells (*zona fasciculata*, *c*). Immediately underneath the capsule, however, the groups are more rounded, and the cells tend to assume a columnar form (*zona glomerulosa*, *b*), whilst next to the medulla they have a reticular arrangement (*zona reticularis*, *d*).

The cells which form the cortical substance are, for the most part, polyhedral in form; each contains a clear round nucleus, and numerous yellowish lipoid globules in the protoplasm. No arteries and veins penetrate between the cells, both these vessels and the lymphatics of the cortex running in the fibrous septa between the cell columns, which they surround with a capillary network. In the zona reticularis the capillaries widen out and occupy sinus-like spaces between the cell columns (fig. 347, *d*). The lymphatics communicate with fine canaliculi between the cells of the cortex.

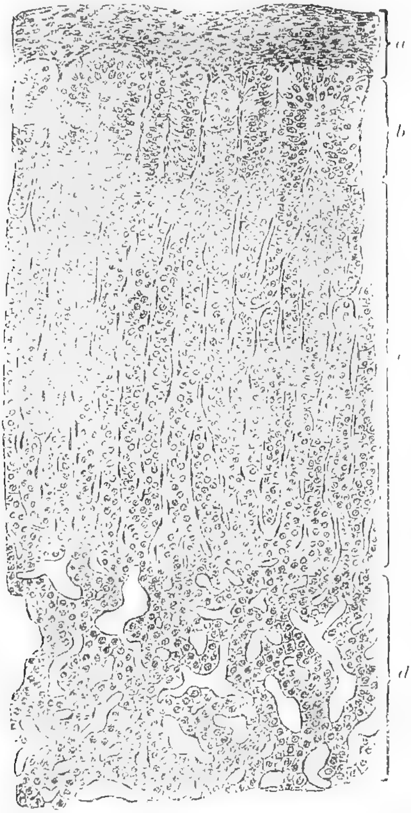

FIG. 347. -VERTICAL SECTION OF CORTEX OF SUPRARENAL OF DOG. (Böhm and v. Davidoff.) Magnified about 150 diameters.

a, fibrous capsule; *b*, zona glomerulosa; *c*, zona fasciculata reticularis; *d*, zo.

The cells of the medulla (figs. 348, 349) are more irregularly disposed. They are supported by a network of elastic fibres. They lie in very close relation to the large capillary blood-spaces (sinusoids) which pervade the medulla, and they probably pour a secretion directly into the blood. Their protoplasm is granular; in some animals it contains a brownish pigment,

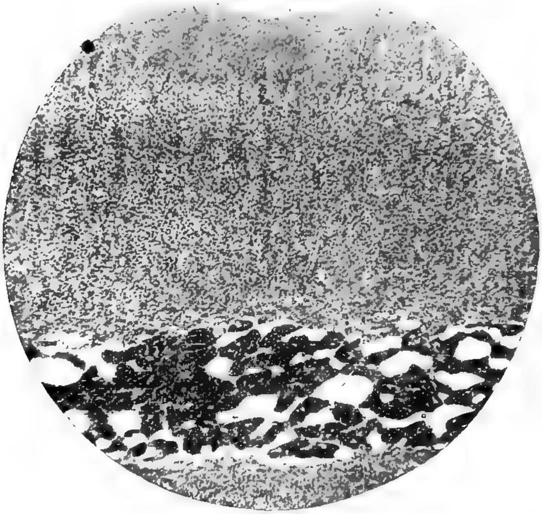

FIG. 348.—PHOTOGRAPH OF SECTION OF SUPRARENAL SHOWING THE MARKED DISTINCTION BETWEEN CORTEX AND MEDULLA. Magnified 40 diameters.

The preparation is stained with bichromate of potassium, and the cells of the medulla are darkly coloured.

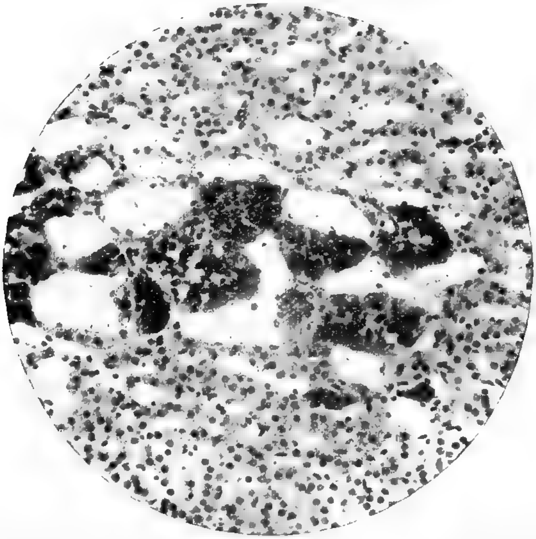

FIG. 349.—PHOTOGRAPH OF PART OF THE SAME SECTION AS THAT SHOWN IN FIG. 348 INCLUDING PORTIONS OF THE ZONA RETICULARIS AND MEDULLA. Magnified 150 diameters.

but in man the dark-red colour of the medulla in the fresh gland is due to the blood contained in the large sinusoid spaces by which it is pervaded, and which receive the blood after it has traversed the capillaries of the cortex. A few arterioles pass straight to the medulla through the cortex. One large vein usually passes out at the hilus in the anterior surface of the gland. Investing the larger veins are longitudinal bundles of plain muscular fibres; but many of the veins have only an endothelium. Numerous nerves, after traversing the cortical substance, are distributed throughout the medulla, where they form a close plexus provided here and there with ganglion-cells. The cells of the medulla are characterised by staining brown by chromic acid and its salts, provided the organ is fresh (*chromaphil or chromaffin reaction*). A similar staining is found to occur in some of the cells of small glandular bodies (*chromaphil bodies, paraganglia*) which occur irregularly at the back of the abdomen, being especially frequent near the lower end of the aorta (fig. 350). A certain number of such cells are also found in sympathetic ganglia (Kohn).

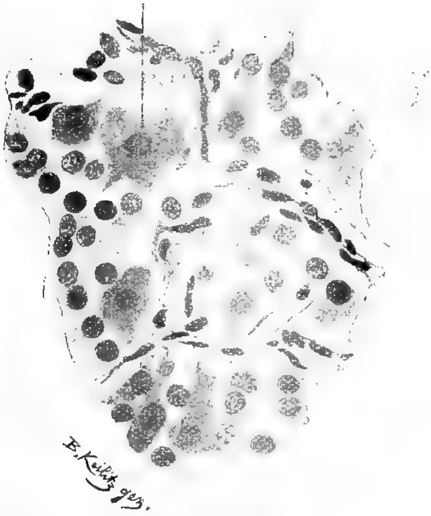

FIG. 350.—SECTION OF PARAGANGLION FROM A NEW-BORN CHILD. (Zuckerkandl.)

Development. The medulla of the suprarenal is developed from cells which become detached from the rudiments of the sympathetic ganglia, and are therefore of ectodermal origin. The cortex is developed from mesoderm.

CAROTID AND COCCYGEAL GLANDS.

These are minute glandular organs without ducts, lying respectively at the bifurcation of the carotid artery and in front of the apex of the coccyx.

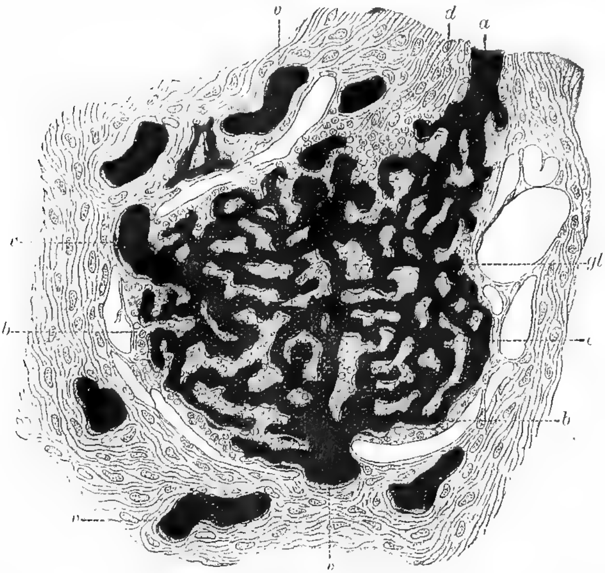

FIG. 351.—A CLUMP OR CELL-BALL FROM THE CAROTID GLAND, INJECTED. (Schaper.)

a, arteriole; *v*, venules; *c*, sinus-like capillary within nodule; *gl*, group of gland-cells; *c*, boundary of nodule surrounded by lymph space; *d*, inter-nodular connective tissue of gland.

They are composed of polyhedral cells (figs. 351 to 353), with numerous blood-capillaries between them. In the carotid gland the cells are collected into spheroidal clumps, in the coccygeal gland into irregular nodules. The blood vessels have a sinus-like character. Amongst the cells, at least in the carotid gland, are some which stain dark brown with chromic acid like those of the medulla of the suprarenal capsules.

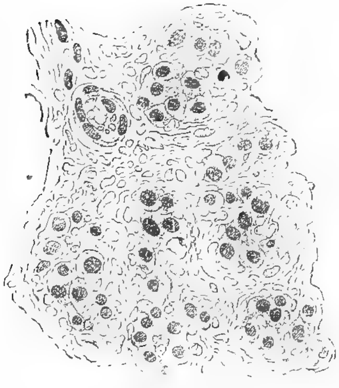

FIG. 352. SECTION OF CAROTID GLAND, HUMAN. Highly magnified. (Schaper.)

THE THYROID BODY.

The **thyroid body** consists of a framework of connective tissue enclosing numerous spherical or oval vesicles (figs. 354, 356) which are lined with cubical epithelium-cells: these often contain granules of a fatty character. The cavities of the vesicles are usually occupied by a peculiar viscid liquid (colloid) which is coagulated by alcohol and which then becomes stained with dyes. The colloid of the thyroid is unique in the fact that it contains organically combined iodine. Colloid has been found in the lymphatics of the gland, and may sometimes be detected also in the interstices of the connective tissue. The amount of colloid accumulated in the vesicles at any one time varies considerably in different individuals; the circumstances which influence its variations are not understood.

There is frequently to be found in connexion with the thyroid a small mass of tissue which resembles the thymus in structure, and, like it, contains concentric corpuscles.

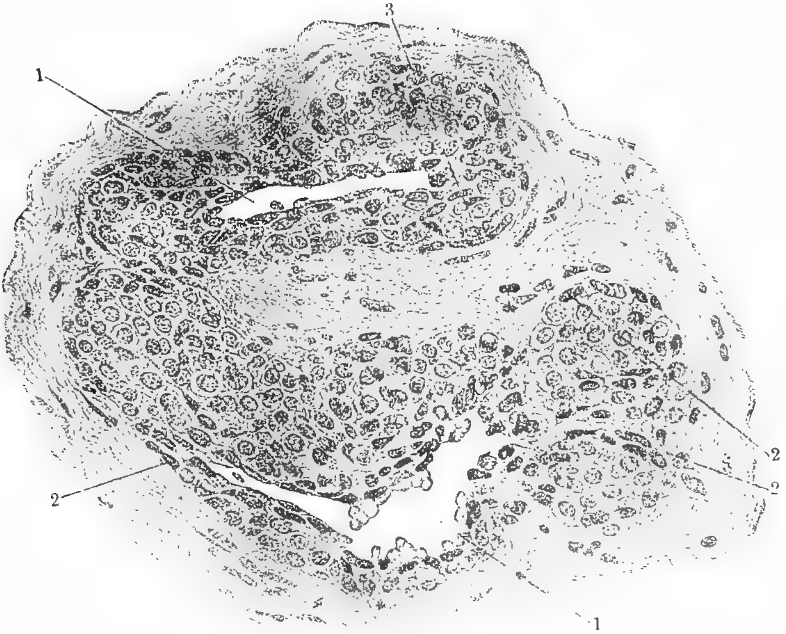

FIG. 353.—SECTION OF COCCYGEAL GLAND. (Walker.)
1, blood-spaces; 2, epithelium; 3, connective tissue.

The blood-vessels of the thyroid are very large and numerous in proportion to the size of the organ. The capillaries form close plexuses round the vesicles (fig. 355), and even extend between the lining epithelium cells.

In endemic goitre colloid accumulates in large quantity in the vesicles which become greatly enlarged so that the gland forms a distinct tumour: nevertheless there is reason to believe that the organ is in an inactive condition. In exophthalmic goitre on the other hand, where there is also enlargement of the organ, this is not accompanied by accumulation of colloid in the vesicles, and these are not much enlarged but become irregular in shape. In this form of goitre the gland shows evidence of increase of activity, accompanied by arterial dilatation.

Development. –The thyroid is formed, like an ordinary gland, by an outgrowth from the buccal epithelium; later, the connexion becomes severed and its branching tubules are broken up into isolated vesicles.

PARATHYROIDS.

In close proximity to or embedded in the substance of the thyroid are always to be found four small glandular organs of different structure from the thyroid proper (figs. 357, 358). These bodies are formed of masses or columns of epithelium cells, some of which are much larger than the rest and are filled with oxyphil granules (Welsh). Numerous sinus-like blood-channels run between the columns and come into close relationship with the cells. Here and there a vesicle filled with a material resembling colloid may be seen amongst the cells and after removal of the thyroid it has been stated that the

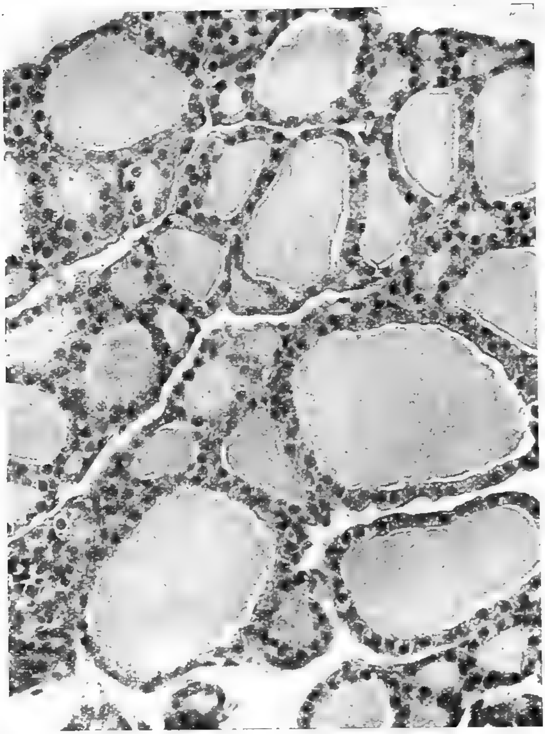

FIG. 354.—SECTION OF THYROID OF CAT. Magnified 400 diameters.
The vesicles are occupied by colloid, which has partly shrunk away from the epithelium. Some of the vesicles are cut tangentially and show only small sectors.

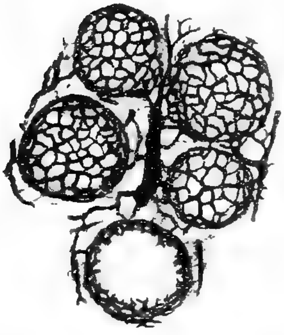

FIG. 355.—VESSELS OF THYROID OF DOG INJECTED.

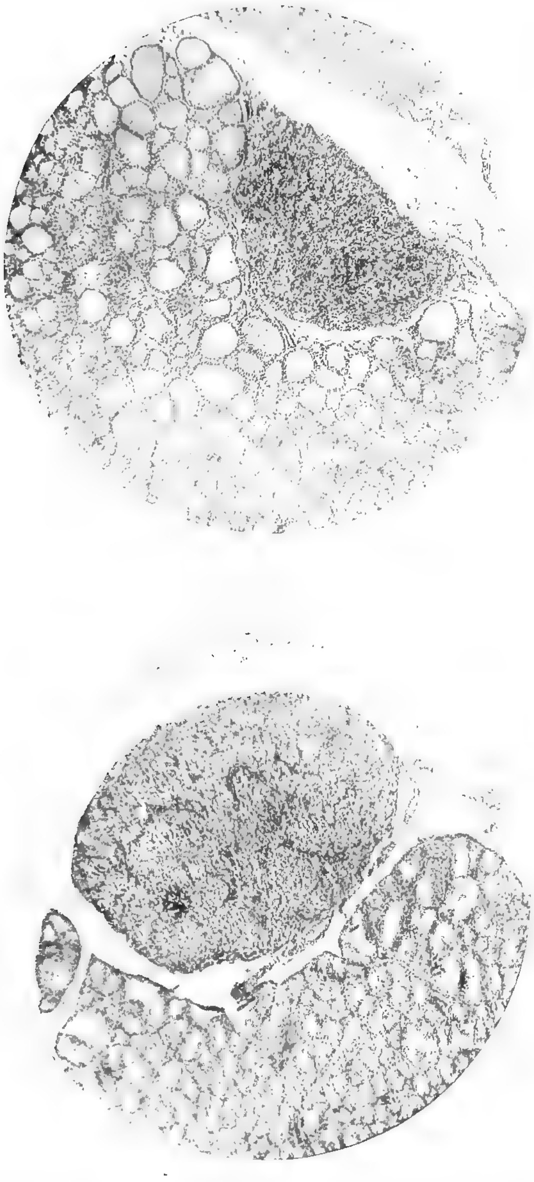

FIG. 356.—TWO SECTIONS OF THYROID AND PARATHYROID OF RAT.
Magnified 50 diameters.

In one of the sections (A) the vesicles of the thyroid are filled with colloid; in the other (B) they are empty and the epithelium is thicker.

parathyroids undergo hypertrophy, and develop a vesicular structure like that of the thyroid, but this appears somewhat doubtful. In cases of myxœdema in the human subject, an affection characterised by atrophy of the thyroid, no such hypertrophy of the parathyroids takes place. The colloid in

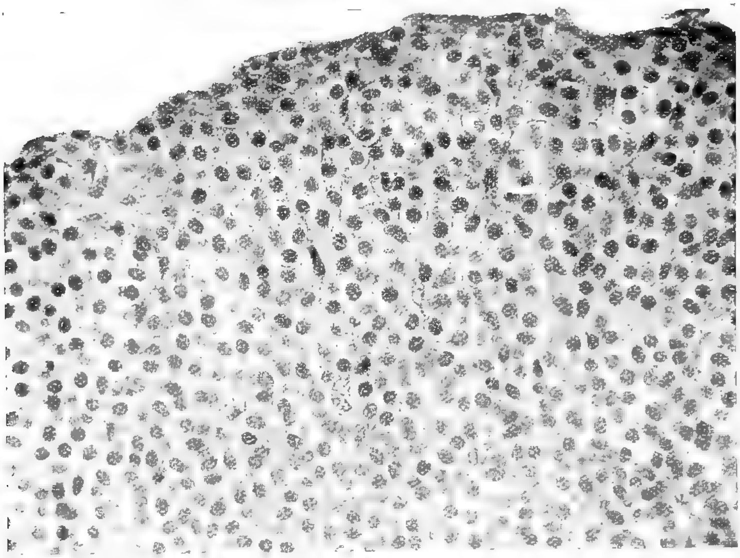

FIG. 357. SECTION OF PARATHYROID OF CAT. Magnified 400 diameters.

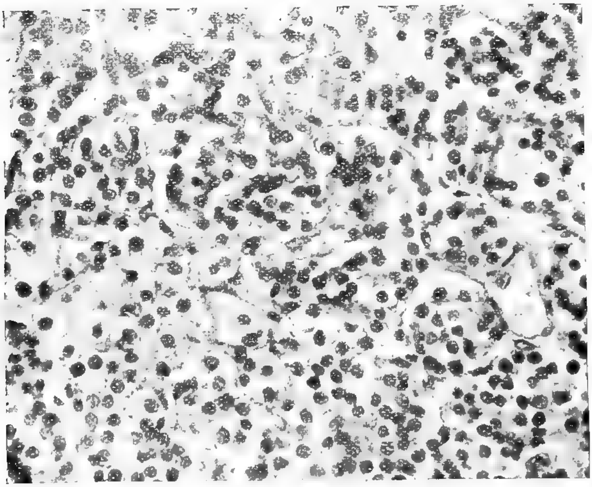

FIG. 358.—SECTION OF HUMAN PARATHYROID. Magnified 400 diameters. (From a preparation by Dr M. Kojima.)

the vesicles is, moreover, when it occurs, not of the same chemical nature as that in the vesicles of the thyroid for it contains no iodine.

Development. The parathyroids are developed, like the thymus, as epithelial outgrowths from certain branchial clefts of the embryo: but they never become converted into lymphoid tissue and are solid from the first. They lose all connexion with the clefts from which they arise, but retain their epithelial structure, although becoming vascularised.

THE PITUITARY BODY.

The **pituitary body** (*hypophysis cerebri*) is a small solid mass, about the size of the kernel of a nut, lying in the sella turcica, and connected with the third ventricle by the infundibulum. It consists partly of epithelium forming the *pars anterior* and *pars intermedia*, partly of nervous tissue, the *pars nervosa.* The epithelium is originally developed as a hollow protrusion of the buccal epithelium. The nervous part is developed in connexion with another hollow outgrowth from the neural ectoderm. The epithelial part consists at an early stage of a number of tubules, lined by epithelium and united by connective tissue, but the lumen of the tubules has become obliterated in the adult, and their place is taken by solid cell-masses. Between the anterior and intermediate parts there is usually a cleft like space containing glairy fluid. It is easy to separate the gland into two portions at this cleft: the posterior portion is composed of pars intermedia and pars nervosa. An extension of the pars intermedia over the tuber cinereum which is developed later than the rest, is termed Tilney *pars tuberalis.*

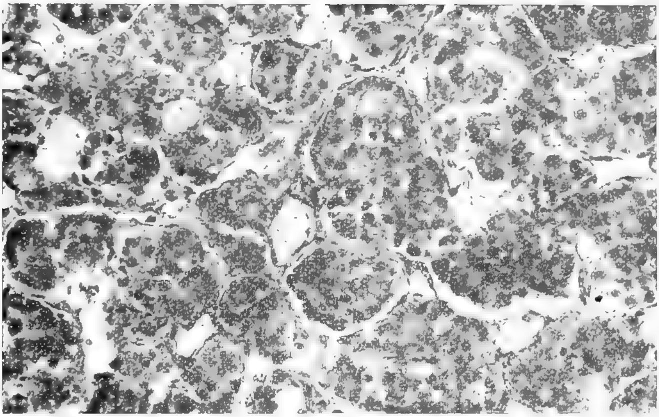

FIG. 359.—SECTION OF PARS ANTERIOR OF PITUITARY, HUMAN. Photograph. Magnified 300 diameters.

The blood-vessels are seen as lighter-looking channels between the darkly stained cell groups.

The *pars anterior* is by far the most vascular portion of the pituitary. Its capillaries have a sinus-like character and occur in large numbers amongst the cells (fig. 359), many of which are set closely round the blood channels.

The cells are of two kinds, clear and granular, varying in relative amount in different glands; the variations being perhaps related to the functional condition of the organ. The granules in the granular cells are generally basiphil, but there are many cells containing oxyphil granules and staining with eosin: these cells become much larger and more numerous during pregnancy. Occasionally the cells of the *pars anterior* are set round closed vesicles containing colloid, but such vesicles are far more common in the pars intermedia.

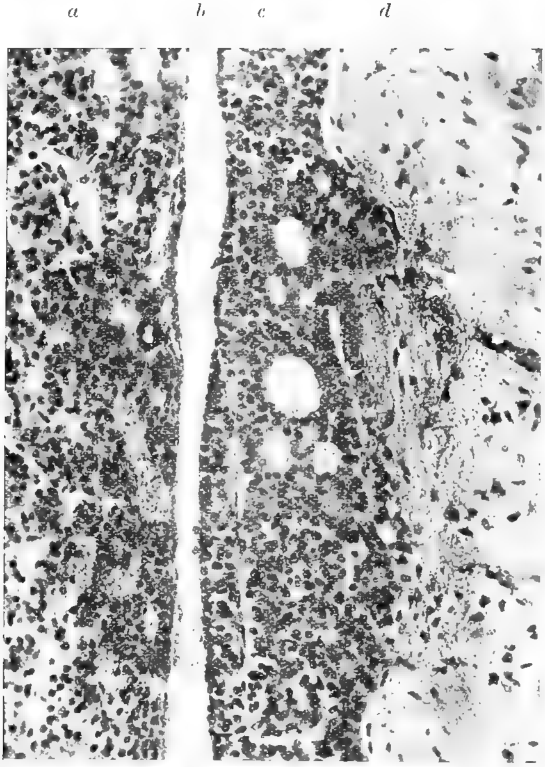

FIG. 360.—SECTION OF PITUITARY OF CAT PASSING THROUGH THE INTRA-GLANDULAR CLEFT. Magnified 200 diameters. (Photographed from a preparation by Dr M. Kojima.)

a, pars anterior with numerous large sinus-like capillaries (seen as clear spaces); *b*, cleft; *c*, pars intermedia showing several vesicles (these are not always present); *d*, pars nervosa.

The *pars intermedia* is less vascular than the pars anterior. Its cells which are clear, without obvious granules, are not infrequently set round colloid containing vesicles scattered here and there in its substance (fig. 360). Above and below the cleft which separates them in the middle of the gland the junction between pars intermedia and pars anterior is not sharply defined. On the other hand the pars intermedia is well marked off from the pars nervosa, except in certain places. At those places its cells are continued into the pars nervosa, either singly or in groups, and there undergo a peculiar degeneration resulting in the formation of hyaline or granular "colloid" substance, which when formed passes through the tissue of the pars nervosa, and is eventually set free in the extension of the third ventricle which projects downwards into the neck of the organ (Herring). This colloid is increased after thyroidectomy, but is not identical with that of the thyroid, for it contains no organically combined iodine (Simpson and Hunter).

The *pars nervosa* of the pituitary body, in spite of its designation, contains in the adult no cells of distinctly nervous character, but is mainly formed of neuroglia elements and of ependyma fibres. It has far fewer blood-vessels than the epithelial parts, but receives a certain number of nerve-fibres which arise from large cells in the grey matter just behind the optic chiasma. Some of these fibres penetrate into the glandular substance of the pars intermedia and pars anterior. Between its elements the hyaline and granular masses of colloid are seen passing towards the infundibulum as just noted (see fig. 361).

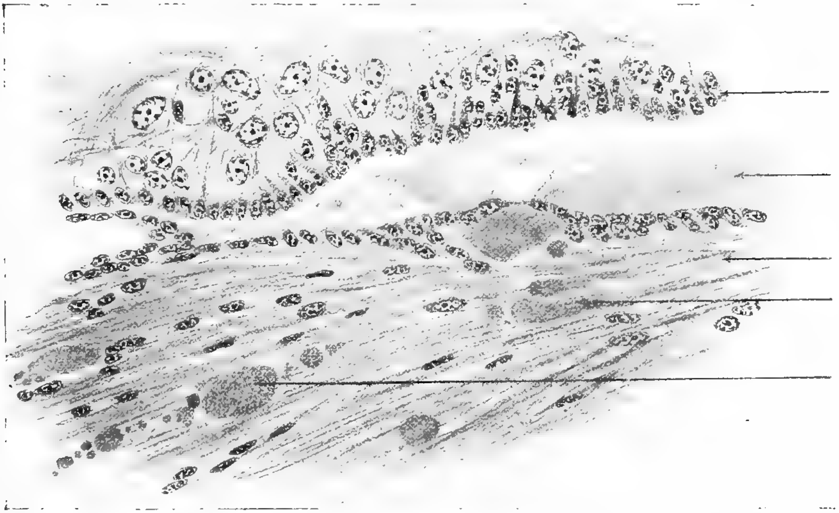

FIG. 361.—SECTION OF PARS NERVOSA OF PITUITARY OF CAT NEAR THE NECK OF THE GLAND. (P. T. Herring.)

a, ependyma cells lining an extension of the infundibulum into the gland; *b*, hyaline masses of colloid within this extension; *c*, ependyma fibres of pars nervosa; *d*, *e*, hyaline and granular colloid passing between these fibres towards the infundibulum.

THE PINEAL GLAND.

The **pineal gland** (*epiphysis cerebri*) is developed as an invagination from the roof of the third ventricle. In the adult it appears as a small reddish body, rounded or conical, attached by a short stalk just above the entrance of the aqueduct of Sylvius into the third ventricle and lying in the groove between the anterior pair of corpora quadrigemina (fig. 362). It is about half the size of the pituitary.

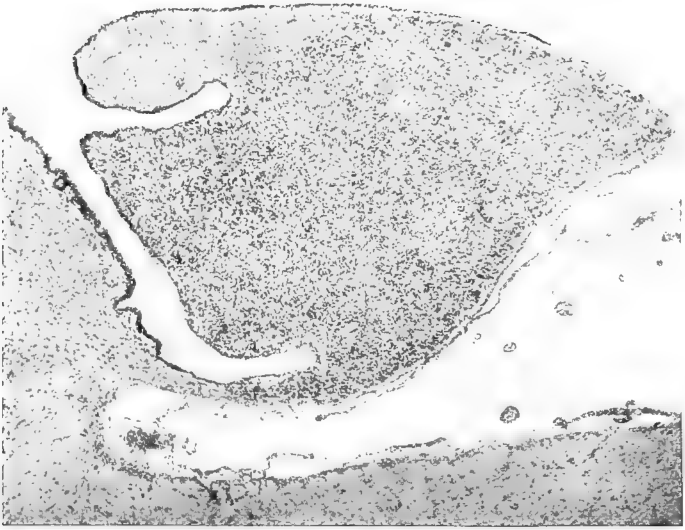

FIG. 362.—SAGITTAL SECTION OF PINEAL OF CAT. Magnified 50 diameters. (Photographed from a preparation by Dr Kojima.)

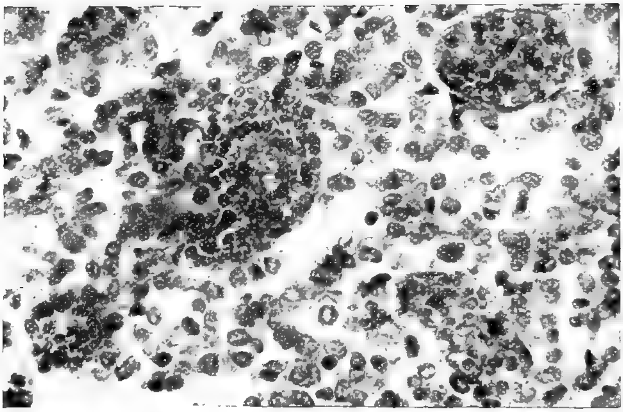

FIG. 363.—SECTION OF PINEAL OF NEW-BORN CHILD SHOWING LOOSELY ARRANGED CELL-TRABECULÆ WITH LARGE BLOOD-VESSELS BETWEEN THEM. The vessels are full of blood-corpuscles which have come out dark in the photograph. Magnified 400 diameters.

The structure of the pineal is best studied in the young subject, for as age advances its distinctive cells become less numerous and a number of calcareous nodules are formed within it, known as *corpora amylacea* (brain sand). These are, however, not special to the pineal but occur in the pia mater and its extensions in various parts of the nervous system.

The gland shows in section masses or trabeculæ of cells with large sinus-like blood-vessels between them (fig. 363): whilst neuroglia cells and fibres are present in abundance in the intrabecular tissue and also between the gland-cells.

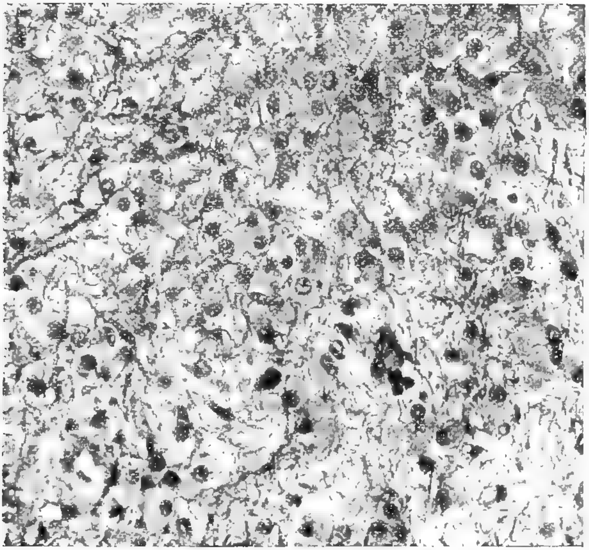

FIG. 364.—SECTION OF OX PINEAL SHOWING THE CELLS MUCH DIMINISHED IN NUMBER WITH MUCH INTERCELLULAR TISSUE RESEMBLING NEUROGLIA. Magnified 300 diameters. (Photographed from a preparation by Mr E. Beard.)

The cells are of two kinds. The majority have oval nuclei and fine oxyphil granules; in the remainder the nuclei are spherical and the granules basiphil. Cells with large oxyphil granules such as frequently occur in the pituitary are not seen in the pineal, nor are vesicles containing colloid observed.

After puberty the gland undergoes retrogressive changes. These consist chiefly in diminution in number of the epithelial-cells and increase in amount of the supporting connective tissue and neuroglia (fig. 364).

LESSONS XXIV. AND XXV.

THE SKIN.

1. Sections of skin from the palmar surface of a finger. The skin is hardened in picric acid or formol, followed by alcohol. The sections are made vertically to the surface, and should extend down as far as the subcutaneous tissue. Notice the layers of the epidermis and their different behaviour to staining fluids. Notice also the papillæ projecting from the corium into the epidermis and look for tactile corpuscles within them. In very thin parts of the sections the fine intercellular channels in the deeper parts of the epithelium (see Lesson VII.) may be seen with a high power. The convoluted tubes of the sweat-glands are visible here and there in the deeper parts of the corium, and in thick sections the corkscrew-like channels by which the sweat is conducted through the epidermis may also be observed. Make a sketch showing the general structure under a low power, and other sketches to exhibit the most important details under a high power. Measure the thickness of the epidermis and the length of the papillæ.

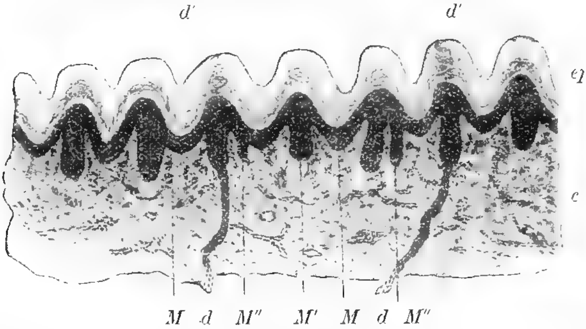

Fig. 365.—Section of skin of heel. (Blaschko.)

ep, epidermis; *c*, cutis vera; *d*, *d*, ducts of sweat glands; *d'*, *d'*, their openings at the surface of the papillary ridge; *M*, Malpighian layer of epidermis thickened opposite the papillary ridges, where it dips down into the cutis vera (at *M'*, *M''*), leaving prominences of the cutis between.

2. Sections of the skin of the scalp (*a*) vertical to the surface and parallel to the slope of the hair-follicles, and (*b*) parallel to the surface, and therefore across the hair-follicles. Stain and mount in the same way as in the last preparation. Examine also the structure of the hairs.

In these preparations the details of structure of the hair and hair-follicles, together with the sebaceous glands and the little muscles of the hair-follicles, are to be made out.

3. Vertical sections of the nail and nail-bed. To cut such hard structures as the nail it is best, after fixing with picric acid or formol followed by 75 per cent. alcohol, to soak the tissue in strong gum arabic for a few days, then place it in an appropriate position upon a cork or upon the object carrier of a microtome, and plunge the whole into 70 per cent. alcohol. This renders the gum hard, and enables sections to be cut of sufficient fineness. A plane iron should be used with the microtome (Cathcart's), since the hardness of the nail will turn the edge of a

razor. To remove the gum the sections are placed in water for a few hours; they may then be stained and mounted. Notice the ridges (not papillæ) of the corium,

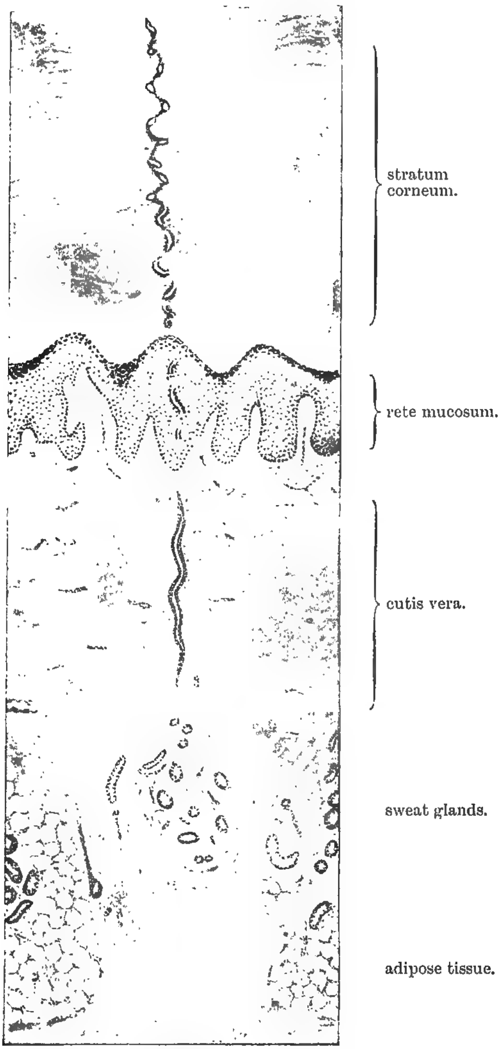

FIG. 366.—VERTICAL SECTION THROUGH THE SKIN OF THE SOLE OF THE FOOT. Magnified about 25 diameters.

projecting into the epidermis. Observe also the distinction of the epidermis into Malpighian layer and nail proper.

4. Mount a section from a portion of skin in which the blood-vessels have been injected, and notice the distribution of the capillaries to the sweat glands, to the hair-follicles, and to the papillary surface of the corium.

5. The cells which compose the nails and hairs can be isolated by warming a small piece of nail or hair in strong sulphuric acid ; after this treatment the cells are readily separated from one another by pressure upon the cover-glass.

6. Sections of mammary gland during lactation. The gland may be fixed either in formol or in Zencker's fluid (see Appendix) and the sections stained with hæmatoxylin and eosin. To show the fat globules within the cells, the gland should be fixed in bichromate of potassium for ten days and a thin piece then transferred to Marchi's fluid (see Appendix) for a few days, after which sections are cut and mounted in dammar, with or without further staining with hæmatoxylin.

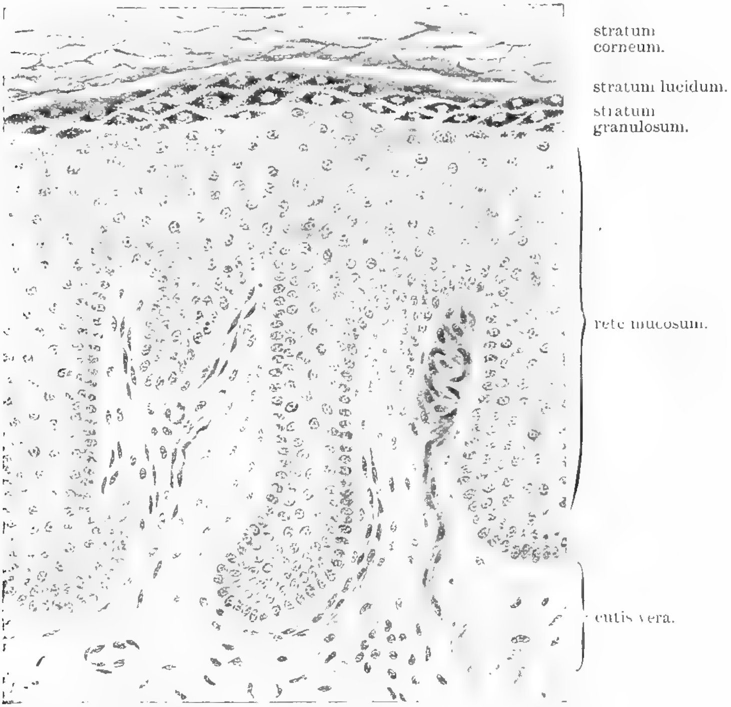

FIG. 367.—VERTICAL SECTION THROUGH THE SKIN OF THE PALMAR SIDE OF THE FINGER, SHOWING TWO OR THREE PAPILLÆ AND THE DEEPER LAYERS OF THE EPIDERMIS. Magnified about 200 diameters.

One of the papillæ contains a tactile corpuscle ; the others blood-vessels.

The **skin** is composed of two parts, *epidermis* and *cutis vera* (figs. 365, 366).

The **epidermis**, or scarf skin, is a stratified epithelium (fig. 367). It is composed of a number of layers of cells, the deeper of which are soft and protoplasmic, and form the *rete mucosum* of Malpighi, whilst the superficial layers are hard and horny, this horny portion sometimes constituting the greater part of the thickness of the epidermis. The deepest cells of the *rete mucosum*, which are set on the surface of the cutis vera, are columnar in shape. In the coloured races of mankind these cells contain pigment-granules. In the layers immediately above them the cells are polyhedral. Between all these cells of the rete mucosum there are fine intercellular clefts (fig. 368) which separate the cells from one another, but are bridged across by fibres which pass from cell to cell, and also through the substance of the cells (fig. 369) (Ranvier, Delépine). The intercellular channels serve for the passage of lymph, and within them lymph-corpuscles may occasionally be found, often having a stellate figure from becoming shaped to the interstices.

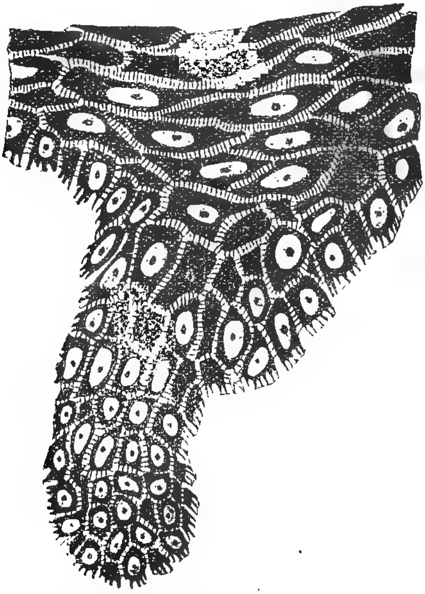

FIG. 368.—SECTION OF EPIDERMIS OF CAT'S FOOT SHOWING INTERCELLULAR CHANNELS, WITH BRIDGING FIBRILS. (Kolossow.)

The superficial layer of the rete mucosum is formed of somewhat flattened cells filled with granules or droplets of a material (*eleidin*) which stains deeply with carmine and hæmatoxylin forming an irregular layer termed *stratum granulosum* (figs. 366, 367, 370, *c*). This is not sharply marked off from the cells of the rete mucosum which lie next to it, for many of these show similar granules, although they less completely fill the cell. Superficial to the stratum granulosum is a layer in which the cell-outlines are indistinct and the cells contain flakes or larger droplets of a hyaline material (*kerato-hyalin*), which stain less intensely than the granules in the last layer, and which tend to run together (fig. 370, *b*). This layer has a clear appearance in section, and is known as the *stratum lucidum*. Immediately superficial to the stratum lucidum is the *horny part* (*stratum corneum*) of the epidermis. It is composed of a number of layers of epithelium-cells, the nuclei of which are no longer visible. These cells, near the surface, take the form of thin horny scales which eventually become detached (fig. 371, *s*). In certain parts which have a thick epidermis and are not covered with hair (*e.g.* the palms and soles), the superficial part of the epidermis is a layer mainly formed by a number of greatly swollen cells (*sw*), forming collectively what has been termed the *epitrichial layer*. In the embryo in the second and third month

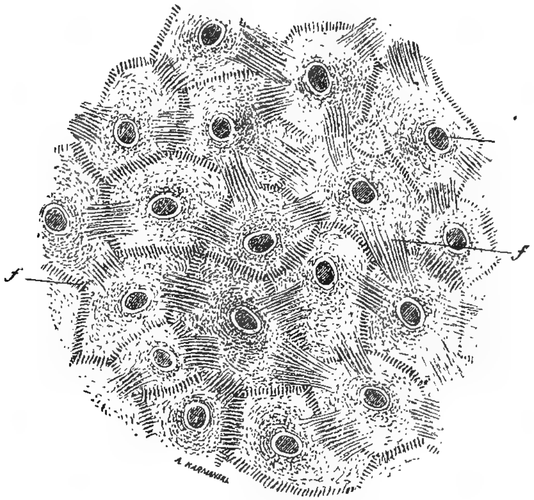

FIG. 369.—SECTION THROUGH THE DEEPER LAYERS OF A STRATIFIED EPITHELIUM, SHOWING FIBRILS, *f*, PASSING FROM CELL TO CELL ACROSS THE INTERCELLULAR SPACES. (Ranvier.)

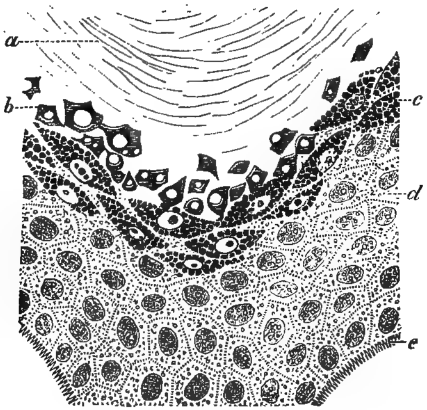

FIG. 370.—PORTION OF EPIDERMIS FROM A SECTION OF THE SKIN OF THE FINGER, COLOURED WITH PICROCARMINE. (Ranvier.)

a, stratum corneum; *b*, stratum lucidum with flakes of kerato-hyalin; *c*, stratum granulosum, the cells filled with drops of eleidin; *d*, prickle-cells; *e*, dentate projections by which the deepest cells of the epidermis are fixed to the cutis vera.

of intrauterine life it covers the whole body, but is thrown off where hairs are developed.

The growth of the epidermis takes place by a multiplication of the cells of the deeper layers. The newly formed cells, as they grow, push towards the surface those which were previously formed, and in their progress the latter undergo a chemical transformation, which converts their fibrillated protoplasm into horny material: this change seems to occur just at and above the stratum granulosum (see fig. 370). The granules of eleidin which occupy the cells of the stratum granulosum are, according to Ranvier, transformed into the *keratin* of the more superficial strata.

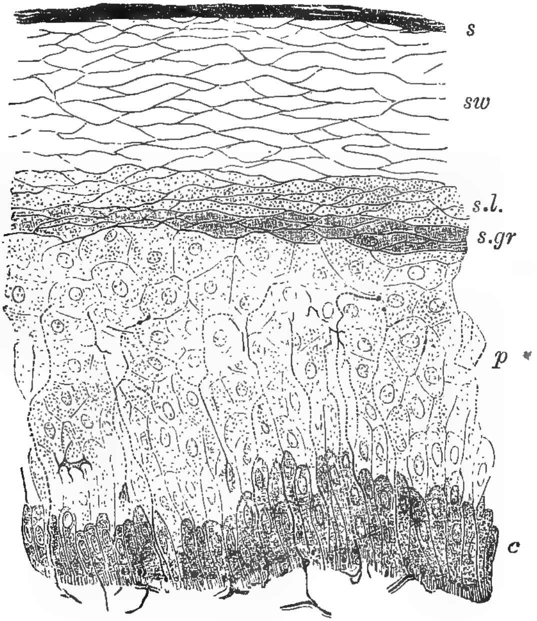

FIG. 371.—SECTION OF EPIDERMIS. (Ranvier.)

s, superficial horny scales; *sw*, swollen horny cells; *s.l.*, stratum lucidum; *p*, prickle-cells, several rows deep; *c*, elongated cells forming a single stratum near the corium; *s.gr*, stratum granulosum of Langerhans just below the stratum lucidum. Part of a plexus of nerve-fibres is seen in the superficial layer of the cutis vera. From this plexus fine varicose nerve-fibrils may be traced passing up between the epithelium-cells of the Malpighian layer.

No blood-vessels pass into the epidermis, but it receives nerves which ramify between the cells of the rete mucosum in the form of fine varicose fibrils (fig. 371). In some parts these are enlarged at their extremity and along their course, into menisci which lie between the deeper epidermis cells. Such terminations are seen in the skin over the pig's snout (fig. 276, p. 198) and in the root-sheaths of hairs (fig. 384). They also occur in the neighbourhood of the entrance of sweat-ducts into the epidermis (Ranvier) (fig. 372).

The **cutis vera** or corium is composed of dense connective tissue, which becomes more open and reticular in texture in its deeper part, where it merges into the subcutaneous tissue. It is thickest over the posterior aspect of the trunk, whereas the epidermis is thickest on the palms of the hand and soles of the feet. The superficial or vascular layer of the corium bears microscopic *papillæ*; these project into the epidermis, which is moulded over them. The papillæ for the most part contain looped capillary vessels, but some, especially those of the palmar surface of the hand and fingers, and the corresponding parts in the foot, contain tactile corpuscles, to which medullated nerve-fibres pass (fig. 367).

In some parts of the body (scrotum, penis, nipple and its areola), involuntary muscular tissue occurs in the deeper portions of the cutis vera; and, in addition, wherever hairs occur, small bundles of this tissue are attached to the hair-follicles.

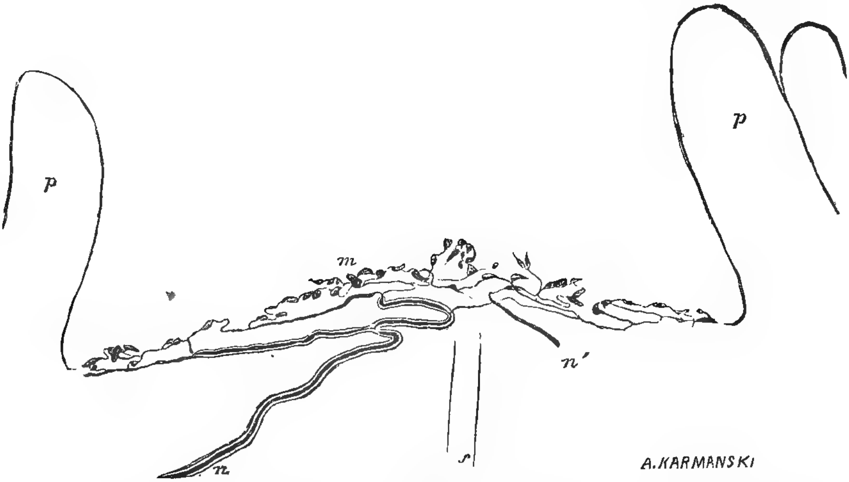

FIG. 372.—SECTION OF THE SKIN OF THE PULP OF THE FINGER OF A CHILD, STAINED WITH GOLD CHLORIDE, SHOWING NERVES TERMINATING IN AN IVY-LIKE ARBORESCENCE AT THE SURFACE OF THE CUTIS VERA AND IN THE DEEPEST PART OF THE EPIDERMIS. (Ranvier.)

p, *p*, outlines of papillæ; *n*, *n′*, nerve-fibres in cutis vera; *m*, terminal menisci; *s*, duct of a sweat gland.

The blood-vessels of the skin are distributed almost entirely to the surface, where they form a close capillary network, sending up loops into the papillæ (fig. 373). Special branches are also sent to the various appendages of the skin, viz. the sweat glands and hair-follicles, with their sebaceous glands and little muscles. Numerous vessels pass to the adipose tissue which is usually found in the deeper parts of the cutis.

The lymphatics originate near the surface in a network of vessels, placed a little deeper than the blood-capillary network. They receive branches from the papillæ, and pass into larger vessels, which are valved, and run in the deeper or reticular part of the corium. From these the

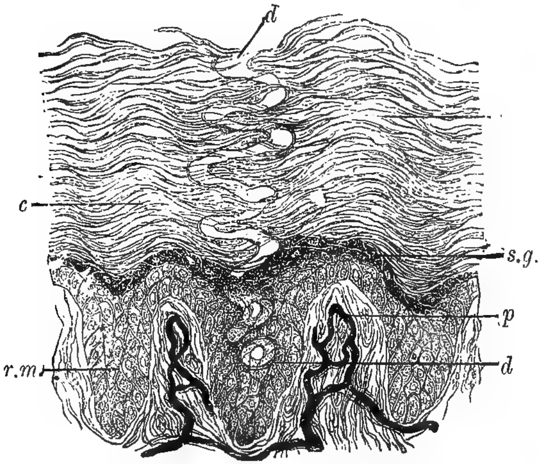

FIG. 373.—DUCT OF A SWEAT GLAND PASSING THROUGH THE EPIDERMIS Magnified 200 diameters. (Heitzmann.)

p, papillæ with blood-vessels injected; *r.m.*, rete mucosum between the papillæ; *c*, *c*, stratum corneum; *s.g.*, stratum granulosum; *d*, *d*, sweat-duct passing through epidermis.

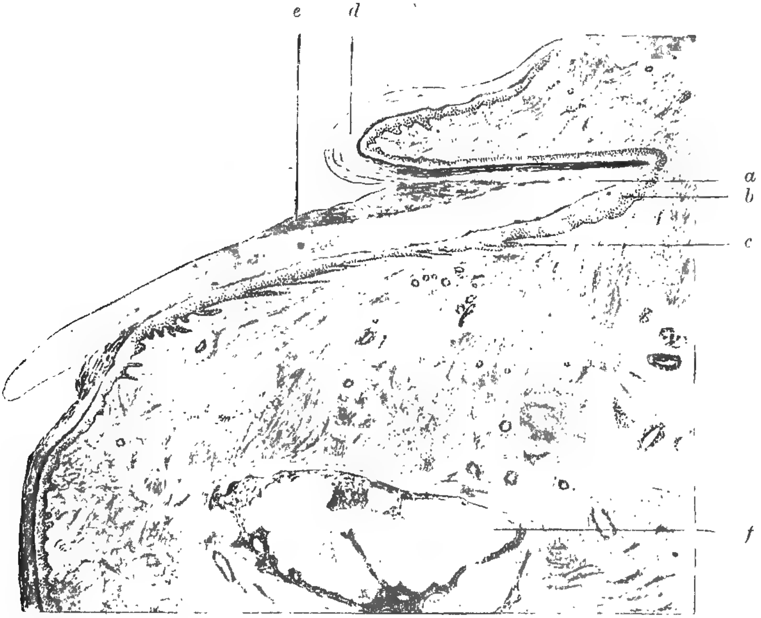

FIG. 374.—LONGITUDINAL SECTION THROUGH THE ROOT OF THE NAIL AND ITS MATRIX. Magnified about 10 diameters.

a, root of nail; *b*, Malpighian layer of matrix; *c*, ridges in dermis of nail bed; *d*, epitrichial layer of epidermis; *e*, eponychium; *f*, bone (terminal phalanx) of finger.

lymph is carried away by still larger vessels, which course in the subcutaneous tissue.

The **appendages of the skin** are the *nails*, the *hairs*, with their *sebaceous glands*, and the *sweat glands*. They are all developed as thickenings and downgrowths of the Malpighian layer of the epidermis.

THE NAILS.

The **nails** are thickenings of the deeper part of the stratum corneum developed over a specially modified portion of the skin (fig. 374), which is known as the *bed of the nail*, the depression at the posterior part of the nail-bed from which the root of the nail grows being known as the *nail-groove*. The part of the bed which occupies the proximal portion of the groove is termed the *nail-matrix*, since it is from this part that the growth of the nail proceeds. The distal part of the nail forms the *free border*, and is the thickest part of the body of the nail. The substance of the nail is composed of clear horny cells, somewhat like the cells of the stratum lucidum of the rest of the epidermis. Each contains the remains of a nucleus. The nail proper rests immediately upon a Malpighian layer similar to that which is found in the epidermis generally, but destitute of a defined stratum granulosum. Nevertheless, the more superficial cells of the rete mucosum contain a large number of special granules, which appear to represent those of the

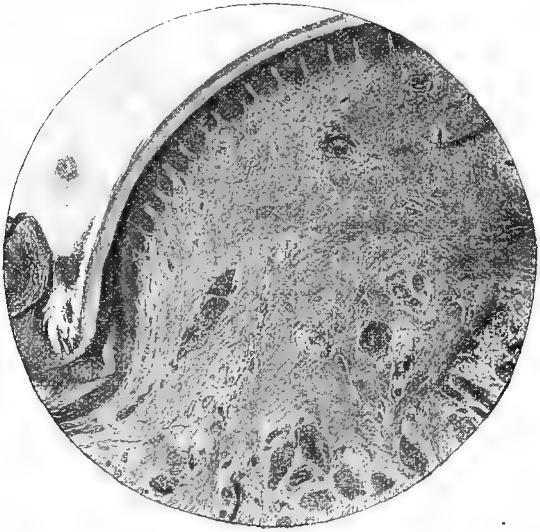
FIG. 375.—TRANSVERSE SECTION ACROSS NAIL TAKEN NEAR ONE EDGE. Magnified 50 diameters.

The apparent papillæ are really sections of ridges or laminæ of the cutis vera projecting into the Malpighian layer of the nail.

stratum granulosum of the epidermis. These granules are, however, not composed of eleidin, but of a material (*onychogenic substance*, Ranvier) which stains brown instead of red with carmine; a similar material occurs in the cells which form the fibrous substance and cuticula of the hairs. The corium of the nail-bed is beset with longitudinal ridges instead of the papillæ which are present over the rest of the skin; these ridges, like the rest of the superficial part of the corium, are extremely vascular.

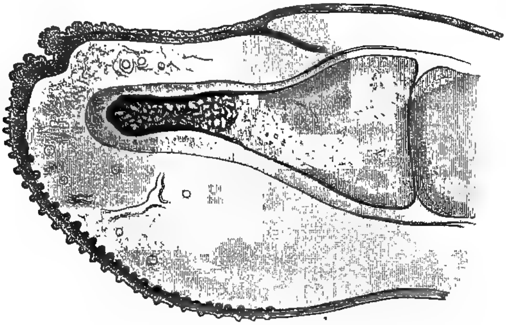

FIG. 376.—SECTION THROUGH END OF FINGER OF HUMAN EMBRYO AT THE TIME OF THE COMMENCEMENT OF FORMATION OF THE NAIL. (Kölliker.)

Notice the ossification of the terminal phalanx beginning at the tip of the cartilage. In the thickened epidermis over this the commencing nail is seen as a dark line.

The nail-bed also receives many nerve-fibres. The deeper of these end in Pacinian corpuscles, whilst others ramify in the ridges of the corium, and some penetrate amongst the epithelium-cells of the Malpighian layer.

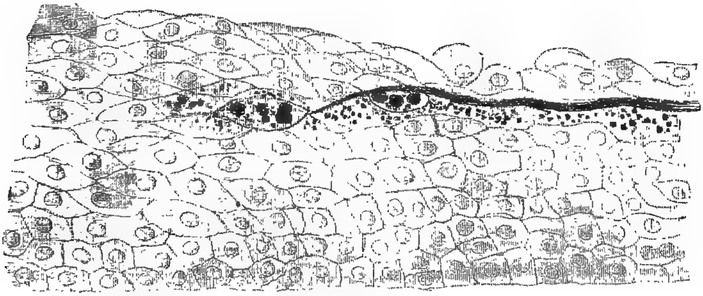

FIG. 377.—FIRST APPEARANCE OF NAIL SUBSTANCE IN THE FORM OF GRANULES OF ONYCHOGENIC MATERIAL IN SOME OF THE CELLS COVERING THE NAIL-BED. (Kölliker.)

Development.—The nails show in the fœtus at about the third month (fig. 376), the groove being formed at this time in the corium, and the nail rudiment appearing in it as a development of onychogenic substance in some of the cells of the epithelium which lies over the bed (fig. 377). It becomes free in the sixth month, its free end being at first thin, but as it grows forward over the bed it receives additions on its under surface—at least in the posterior part of the bed—so that after a time the distal end becomes thicker. The epitrichial layer of the cuticle which originally covered the developing nail becomes detached after the fifth month, and, after birth, only remains as the narrow border of free cuticle (*eponychium*) which overlies the root.

HAIRS.

The **hairs** are growths of the epidermis, developed in deep pits—the *hair-follicles*—which extend downwards into the thickness of the corium, or even into the subcutaneous tissue. The hair grows from the bottom of the follicle, the part which lies within the follicle being known as the *root.*

The substance of a hair is mainly composed of a pigmented, horny, *fibrous material* (fig. 378, *f*), which can be separated by the action of sulphuric acid into long tapering fibrillated cells, the nuclei of which are still visible. The fibrous substance of the hair is covered by a layer of delicate imbricated scales, termed the *hair-cuticle* (*c*). In many hairs, but not in all, the centre is occupied by an axial substance (*medulla*, *m*), formed of angular cells which contain granules of eleidin, and frequently have a dark appearance from the presence of minute air-bubbles. The latter may also occur in interstices in the fibrous substance. When air is present, the hair looks dark by transmitted, white by reflected light. The *root* has the same structure as the body of the hair, except at its deep extremity, which is enlarged to form the hair-bulb; this enlargement is composed mainly of soft, growing cells, and fits over a vascular *papilla*, which projects up into the bottom of the follicle (fig. 379).

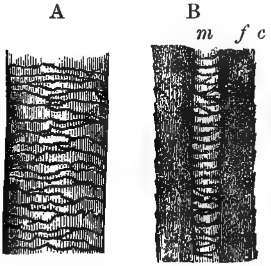

FIG. 378.—PIECE OF HUMAN HAIR. Magnified.

A, seen from the surface; *B*, in optical section; *c*, cuticle; *f*, fibrous substance; *m*, medulla, the air having been expelled by Canada balsam.

Structure of hair-follicle (figs. 379 to 382).—The follicle, like the skin itself, of which it is a recess, is composed of two parts: one epithelial, the other connective tissue. The epithelial or epidermic part of the follicle closely invests the hair-root, and is often in great part dragged out with it; hence it is known as the *root-sheath.* It consists of an outer layer of soft columnar and polyhedral cells, like the Malpighian layer of the epidermis, but without stratum granulosum—the *outer root-sheath*; and of an inner, thinner, horny stratum next to the hair—the *inner root-sheath.* The inner root-sheath itself consists of three layers, the outermost being composed of horny, fibrous, oblong cells the nuclei of which are obscure and difficult to make out (*Henle's layer*), the next of polyhedral nucleated cells containing eleidin (*Huxley's layer*), and the third—the *cuticle of the root-sheath*—a layer of downwardly imbricated scales, which fit over the upwardly imbricated scales of the hair itself. In the more superficial part of the hair-follicle the layers of Huxley and Henle are indistinguishable, the cells of both being clear and keratinised; even lower down where distinguishable they show a tendency to dovetail into one another. At the bottom of the follicle no differentiation into layers can be made out in the root-sheath, which is here formed by a uniform mass of soft cells surrounding the papilla.

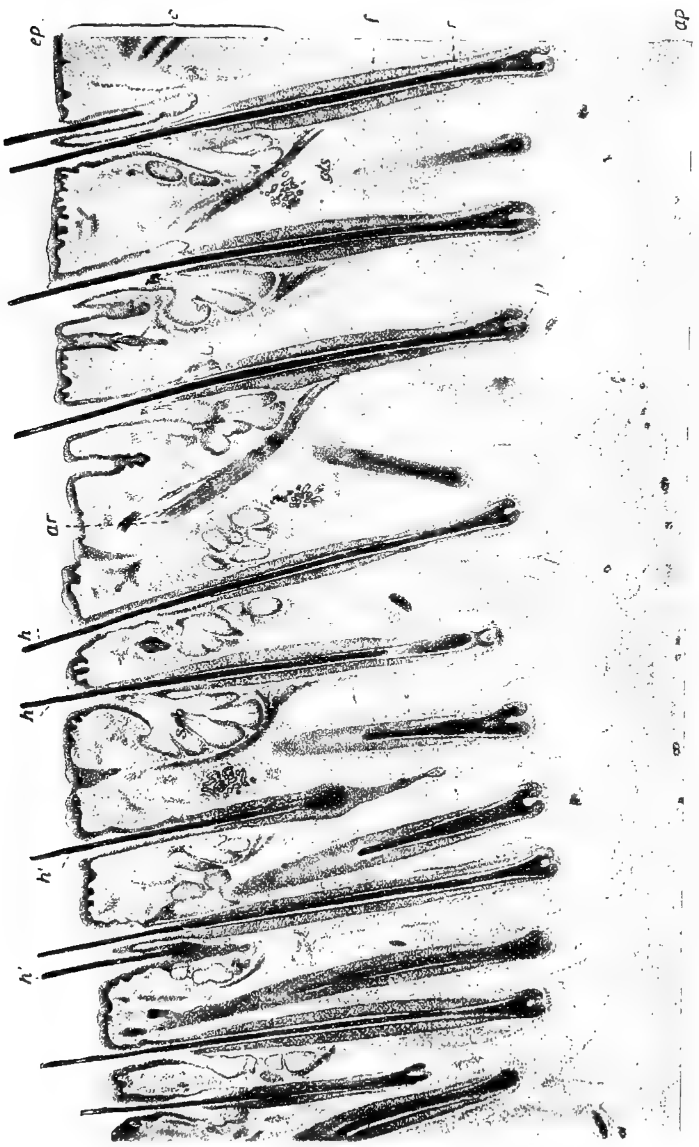

Fig. 379.—Section of human scalp (after Sobotta). Magnified 14 diameters.

h, *h*, ordinary or bulb-hairs; *h'*, *h'*, club hairs; *ar*, arrector pili muscle; *f*, a hair-follicle; *r*, root of hair; *p*, papilla; *ep*, epidermis; *c*, cutis vera; *ap*, aponeurosis below subcutaneous tissue; *gls*, sweat glands; *se'*, sebaceous glands.

In the greater extent of the follicle the outer root-sheath is several layers deep, but as the bottom of the follicle is approached it becomes thinner, and is finally reduced to a single stratum of cells which becomes flattened out into a very thin layer in the papillary part (fig. 380, I.).

The connective tissue or dermic part of the hair-follicle is composed internally of a vascular layer, which is separated from the root-sheath by a basement-membrane termed the *hyaline layer* of the follicle. This inner vascular layer corresponds to the superficial layer of the cutis vera. Its fibres and cells have a regular circular arrangement around the follicle, the cells being flattened against the hyaline layer. Externally the dermic coat of the follicle has a more open texture, corresponding to the deeper part of the cutis, and contains the larger branches of the arteries and veins. In

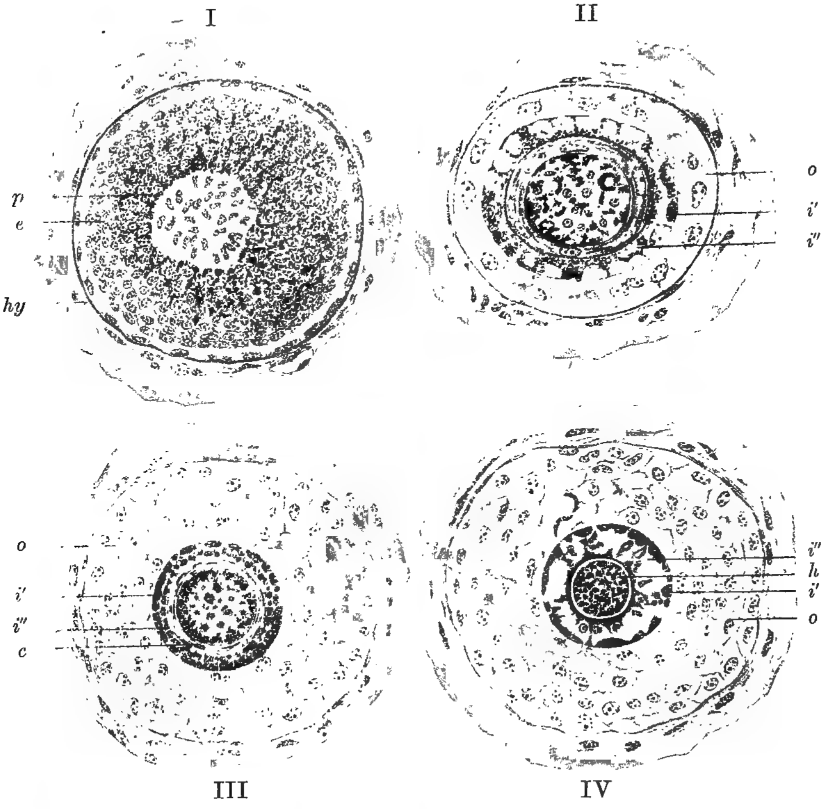

FIG. 380.—SECTIONS ACROSS HAIR-FOLLICLES FROM THE SCALP OF AN INFANT.

1. Through papilla. II. Just above papilla. III. About middle of follicle. IV. Near outer part of follicle. In I. :—*p*, papilla ; *e*, epithelium surrounding papilla, with pigment in cells ; *hy*, hyaline layer of dermic coat with thin outer root-sheath just within it. In II., III., IV. :—*o*, outer root-sheath ; *i'*, layer of Henle, and *i''*, layer of Huxley of the inner root-sheath ; *c*, cuticle of root-sheath ; *h*, hair.

the large tactile hairs of animals, the veins near the bottom of the follicle are dilated into sinuses, forming a kind of erectile structure.

The hair-follicle receives nerve-fibres which pass into the papilla, and others which enter the root-sheath. These last are derived from the superficial nerves of the corium and form ring-like arborisations in the upper part of the hair-follicle. They are especially well developed in the large tactile hairs (whiskers) of animals.

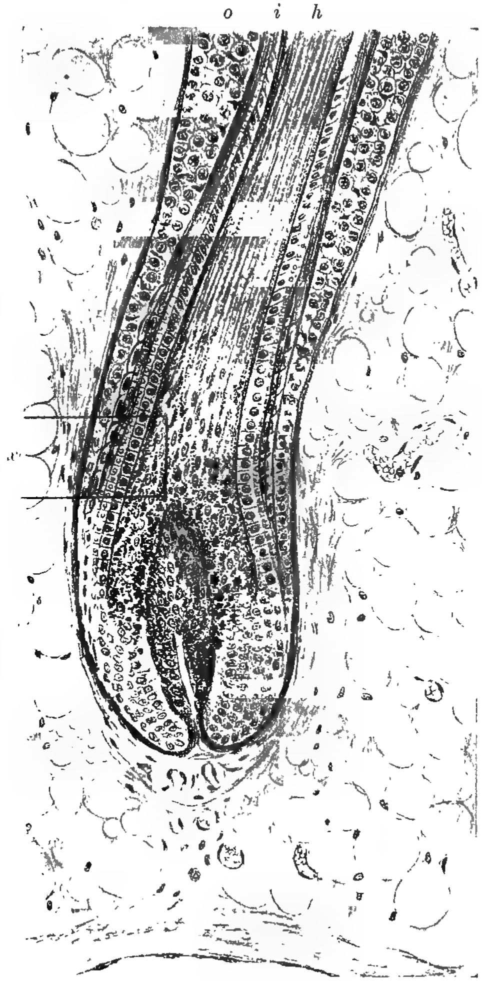

Fig. 381.—Longitudinal section of a hair-follicle. Magnified 200 diameters. *o*, outer; *i*, inner root-sheath; *h*, hair; *x*, part shown magnified in fig. 382.

The hair grows from the bottom of the follicle by multiplication of the soft cells which cover the papilla, these cells becoming elongated and pigmented to form the fibres of the fibrous substance, and otherwise modified to produce the medulla and cuticle of the hair and the several layers of the root-sheath. The cells which form the medulla of the hair and the inner root-sheath are filled with granules of eleidin, but those which form the fibrous substance and cuticula of the hair have granules which stain brown with carmine, and appear similar to the granules in the corresponding cells of the nail-matrix (Ranvier) (see p. 271).

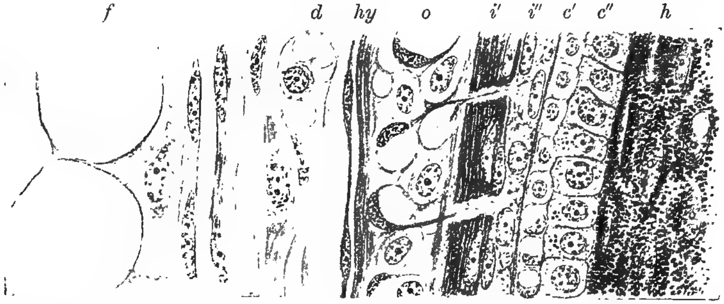

FIG. 382.—A SMALL PORTION OF THE SECTION SHOWN IN FIG. 381 ENLARGED TO EXHIBIT THE STRUCTURE OF THE SEVERAL LAYERS.

h, hair; *c''*, its cuticle; *c'*, cuticle of root-sheath; *i''*, Huxley's layer; *i'*, Henle's layer; *o*, outer root-sheath; *hy*, hyaline layer; *d*, dermic coat; *f*, fat-cells.

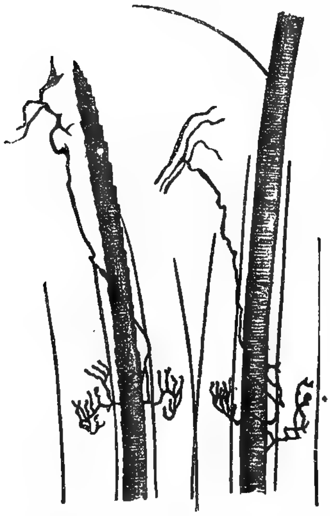

FIG. 383.—FROM A SECTION OF SKIN PREPARED BY THE CHROMATE OF SILVER METHOD, SHOWING THE UPPER PART OF TWO HAIRS AND THE TERMINAL ARBORISATIONS OF NERVE-FIBRES IN THEIR ROOT-SHEATHS. (Van Gehuchten.)

On the side to which the hair slopes a small patch of richly innervated thickened epidermis is usually to be found, developed over an enlarged papilla of the cutis vera: while on the opposite side of the hair is a flat area of skin with thickened scale-like epidermis, which may represent a vestige of the reptilian scale (Pinkus).

The hair-germs when they first appear (as at *a*, fig. 387) are singularly like certain tactile patches which are found in the skin of amphibia and some reptiles, and it is possible that hairs have become developed phylogenetically from these patches. It is well known that the tactile sensibility of many parts of the skin is intimately associated with the hairs, although parts devoid of hairs may also have a highly developed sense of touch.

Besides the hairs which have been described, and which are provided with a vascular papilla from the cells on the surface of which the hair and its inner root-sheath grow (*growing or bulb hairs, papillated hairs*), there are many which are unprovided with a papilla and the follicle of which ceases at the level of attachment of the arrector pili muscle (*non-growing or club-hairs, non-papillated hairs*). These are hairs which have become detached from their papilla and have ceased to grow; they are more easily pulled out than the growing hairs, and after a time tend to fall out spontaneously. In their follicles the whole of the lower part of the hair, including the original papilla and the soft growing cells which cover it, may entirely disappear, the hair being now attached at its sides and below to the root-sheath (fig. 379, *h'*). A hair which has thus ceased to grow eventually becomes lost, but its place is presently supplied by a new hair, which becomes developed in a down-growth from the old follicle, a new papilla becoming formed at the extremity of the down-growth (figs. 385, 386). If not previously detached, the old hair is pushed out from the follicle by the one which replaces it.

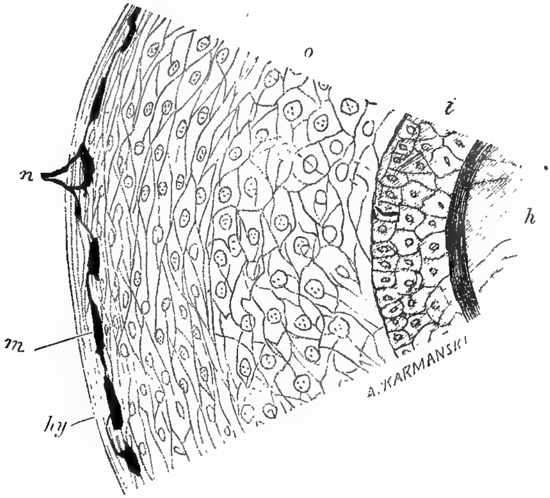

Fig. 384.—Nerve ending in outer root-sheath of tactile hair of rabbit. (Ranvier.)

n, nerve-fibre; *m*, tactile meniscus; *o*, outer root-sheath; *i*, inner root-sheath; *h*, hair; *hy*, hyaline membrane.

The detachment of the non-papillated hairs is preceded by an absorption of the root of the hair and of the investing inner root-sheath. This absorption appears to be effected by the cells of the outer sheath, which multiply at the expense of the keratinised parts of the hair root and undermine its attachment to the follicle (fig. 385).

Development.—The hairs are originally developed in the embryo as small solid down-growths from the Malpighian layer of the epidermis (fig. 387). The hair-germ, as it is called (although it gives rise not only to the hair proper but also to the epithelium-cells of the hair-follicle), is at first composed entirely of soft growing cells, the outermost and deepest having a columnar shape; but presently those in the centre become differentiated, so as to produce a minute hair invested by inner root-sheath, its base resting upon a papilla which has become enclosed by the extremity of the hair-germ and which is continuous with the connective tissue of the corium (fig. 388). As the minute hair grows, it pushes its way through the layers of the epidermis, which it finally perforates, the epitrichial layer being thrown off (p. 266). During the whole process the follicle is growing more deeply into the cutis vera, carrying the papilla down with it.

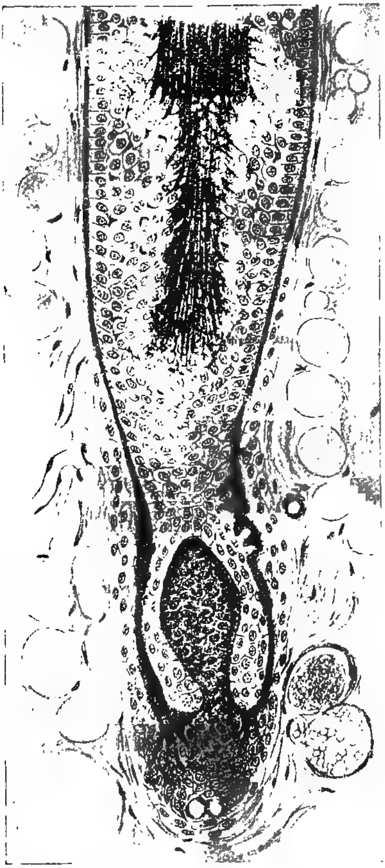

FIG. 385.—LONGITUDINAL SECTION THROUGH THE FOLLICLE OF A HAIR WHICH HAS CEASED TO GROW AND THE ROOT OF WHICH IS UNDERGOING ABSORPTION. Magnified 200 diameters.

The hair-rudiments begin to appear at the third or fourth month of fœtal life; their growth is completed about the fifth or sixth month, and the fine hairs which they form constitute a complete hairy covering termed the *lanugo*. This is entirely shed within a few months of birth, the new hairs being formed in down-growths from the old hair-follicles in the manner already mentioned.

Hairs grow at the rate of about half an inch per month. They are found all

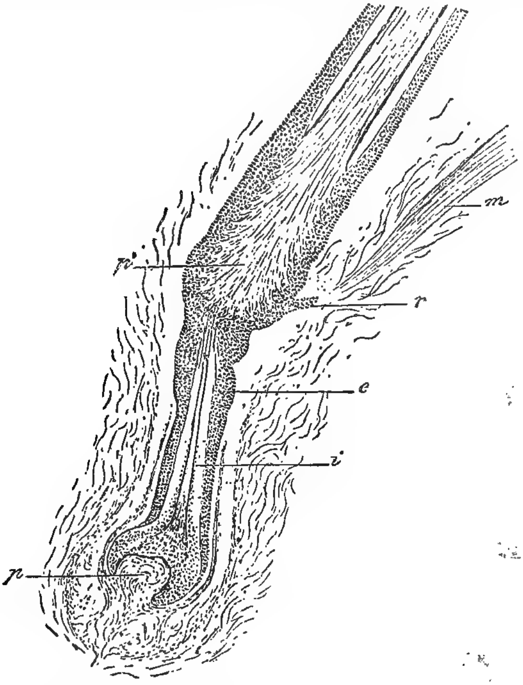

FIG. 386.—FORMATION OF A NEW HAIR IN A DOWN-GROWTH FROM A FOLLICLE IN WHICH THE OLD HAIR IS BECOMING SHED. (Ranvier.)

p, papilla of new hair; *i*, *e*, its inner and outer root-sheaths; *p'*, root of old hairs; *r*, epithelial projection at attachment of arrector pili, *m*.

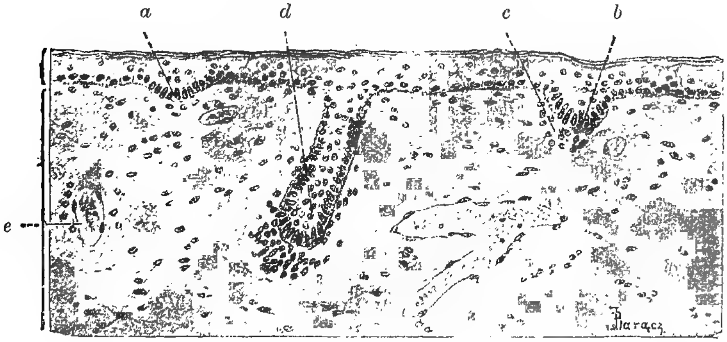

FIG. 387.—HAIR-GERMS IN A SECTION OF THE SCALP OF A HUMAN FŒTUS. (Szymonowicz.) Magnified 230 diameters.

a, commencing down-growth of epidermis; *b*, further stage of down-growth; *c*, connective-tissue cells beginning to accumulate to produce the dermic coat of the follicle; *d*, hair-follicle more advanced in development; *e*, section of a blood-vessel.

over the surface of the body except on the palms of the hands and the soles of the feet, including the fingers and toes, the dorsal surface of the distal phalanges of the fingers and toes, and certain parts of the external generative organs. They usually slant, and in the negro the hair-follicles are even considerably curved. On the scalp they are set in groups, as is well seen in a horizontal section; they are most numerous here (200 to 300 per square centimeter).

The hairs of animals are often curiously marked by the arrangement of their medulla, the markings being characteristic of particular species. In the mole, the hairs have a varicose form with alternate enlargements and constrictions. In human hair the disappearance of the papilla is preceded by its gradual diminution in size, and during this period the root of the hair is becoming gradually more slender (Ranvier), so that when such a hair is pulled out it appears to be of least diameter near the bulb, instead of being largest there, as is the case under ordinary circumstances.

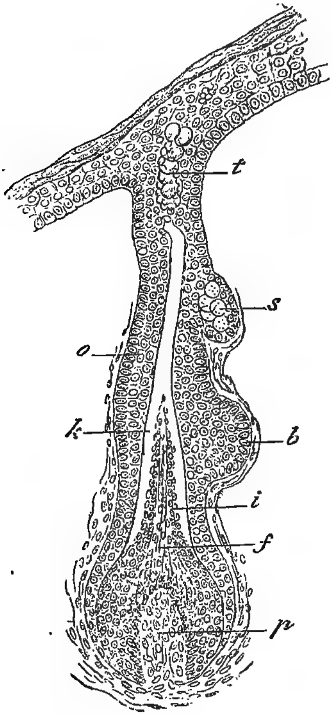

FIG. 388.—DEVELOPING HAIR FROM HUMAN EMBRYO OF FOUR AND A HALF MONTHS. (Ranvier.)

p, papilla; *f*, hair-rudiment; *i*, cells from which the inner root-sheath is becoming formed; *k*, keratinised part of inner root-sheath, uncoloured by carmine; *o*, outer root-sheath; *b*, epithelial projection for insertion of arrector pili; *s*, sebaceous gland; *t*, sebaceous degeneration of cells in the part which will become the neck of the follicle. This forms a channel for the passage of the hair-point through the Malpighian layer.

Muscles of the hairs.—A small muscle composed of bundles of plain muscular tissue is attached to each hair-follicle (*arrector pili*, fig. 379, *ar*); it passes from the superficial part of the corium, on the side to which the hair slopes, obliquely downwards, to be attached near the bottom of the follicle to a projection formed by a localised hypertrophy of the outer root-sheath. When the muscle contracts, the hair becomes more erect, and the follicle is dragged upwards so as to cause a prominence on the general surface of the skin, whilst the part of the corium from which the little muscle arises is correspondingly depressed; the roughened condition known as "goose skin" being in this way produced. There is always a sebaceous gland in the triangle formed between the arrector pili, the mouth of the hair-follicle, and the epidermis, so that the contraction of the arrector generally causes the secretion of the gland to be extruded. These small muscles are supplied by nerve-fibres derived from the sympathetic.

GLANDS OF THE SKIN.

The **sebaceous glands** (fig. 379, *seb*) are small saccular glands, the ducts from which open into the mouths of the hair-follicles. They are also found in a few situations which are devoid of hairs (margin of lips, parts of the external generative organs). The Meibomian glands of the eyelid are modified sebaceous glands. Both the duct and the saccules are lined by epithelium, which becomes charged with fatty matter. This sebaceous matter is discharged into the cavity of the saccule, probably owing to the disintegration of the cells within which it is formed. There may be more than one sebaceous gland attached to each hair-follicle.

The sebaceous glands are developed as outgrowths from the outer root-sheaths of the hairs (fig. 388, *s*).

The **sweat glands** are abundant over the whole skin, but they are most numerous on the palm of the hand and on the sole of the foot. They are composed of coiled tubes, which lie in the deeper part of the integument and send their ducts up through the cutis to open on the surface by cork-screw-like channels in the epidermis (fig. 389).

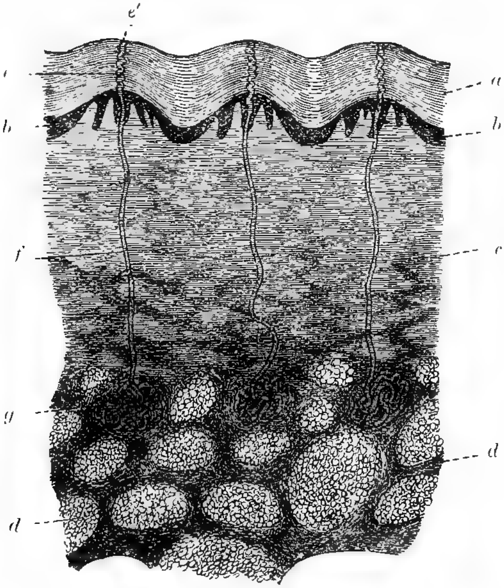

FIG. 389.—SECTION OF SKIN OF PALM, SHOWING POSITION OF SWEAT GLAND. (Kölliker.)

a, *b*, epidermis; *c*, cutis vera; *d*, subcutaneous adipose tissue; *e*, channel passing through epidermis; *e′*, its orifice; *f*, duct of gland passing through cutis vera; *g*, coiled tubes of sweat gland.

The *secreting part of the gland* is formed of a convoluted tube composed of a basement-membrane lined by a single layer of cubical or columnar epithelium-cells, and with a layer of longitudinally or obliquely disposed fibres between the epithelium and basement-membrane (fig. 390). These fibres are usually regarded as muscular, although the evidence on this point is not conclusive. The secreting tube is considerably larger than the duct,

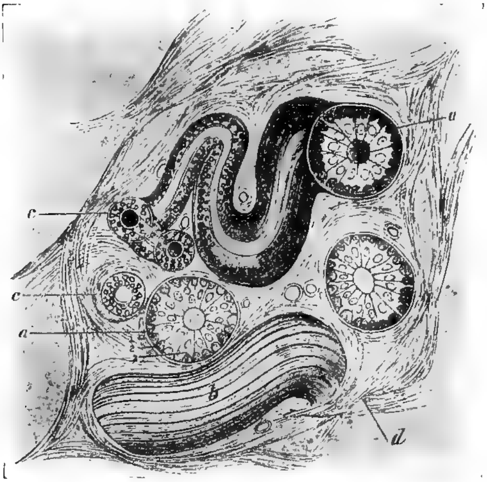

FIG. 390.—SECTION OF A SWEAT GLAND IN THE SKIN OF MAN.

a, *a*, secreting tube in section; ***b***, a coil seen from above; *c*, *c*, efferent tube; ***d***, intertubular connective tissue with blood-vessels. 1, basement-membrane; 2, muscular fibres cut across; 3, secreting epithelium of tubule.

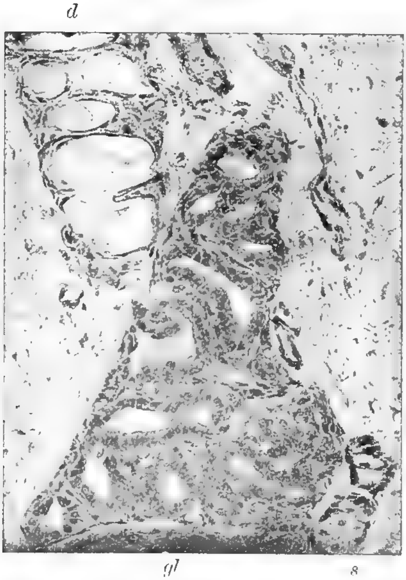

FIG. 391.—SECTION OF CERUMINOUS GLAND OF THE EXTERNAL EAR. Photograph.

d, duct of gland; it has a spiral course and is therefore cut several times; it is partly filled with cerumen; *gl*, secreting tubules of gland; *s*, extremity of a tubule of a sebaceous gland which extended as far as the base of the ceruminous gland.

which begins within the gland and usually makes several convolutions before leaving the gland to traverse the cutis vera. The duct has an epithelium consisting of two or three layers of cells, within which is a well-marked cuticular lining, but there is no muscular layer. The passage through the epidermis has no proper wall, but is merely a channel excavated between the epithelium-cells. Very large sweat glands occur in the axilla.

The sweat glands receive nerve-fibres, and each gland has a special cluster of capillary blood-vessels.

The **ceruminous glands of the ear** (fig. 391) are modified sweat glands. The secretion is of a sebaceous nature, instead of being watery like that of the ordinary sweat glands. The ceruminous glands are closely associated with large sebaceous glands (fig. 392).

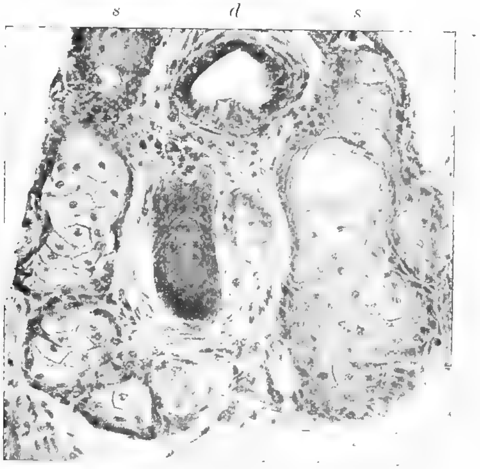

Fig. 392.—Section showing the duct of a ceruminous gland accompanied by the secreting tubules of large sebaceous glands. Photograph.

Development.—The sweat glands are developed, like the hairs, as downgrowths of the Malpighian layer of the epidermis into the corium. They are distinguishable from the hair-germs by the fact that the cells of the outermost layer are not columnar in shape, but spheroidal or polyhedral. The sweat gland germs which are thus formed become eventually coiled up at their extremities and converted into hollow tubes. The muscular fibres of the tubes as well as the secreting epithelium-cells are ectodermic structures.

THE MAMMARY GLANDS.

The **mammary glands** are compound racemose glands which open by numerous ducts upon the apex of the nipple. The ducts are dilated into small reservoirs just before reaching the nipple (fig. 393). If traced backwards, they are found to commence in groups of saccular alveoli (fig. 394).

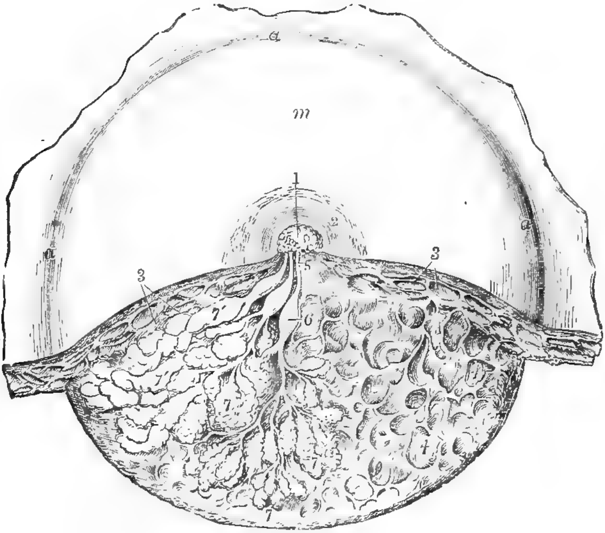

FIG. 393.—A MAMMARY GLAND DISSECTED TO SHOW THE DUCTS DILATED INTO RESERVOIRS BEFORE OPENING UPON THE NIPPLE.

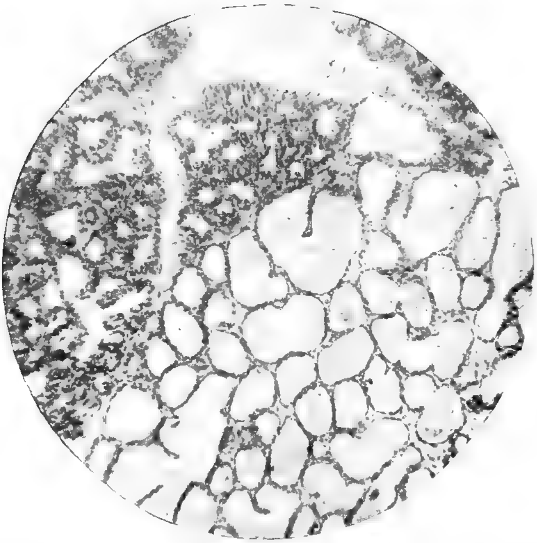

FIG. 394.—SECTION OF TWO ADJACENT MAMMARY GLANDS OF LACTATING CAT, ONE OF WHICH IS FULL OF MILK WHILST THE OTHER HAS BEEN EMPTIED OF ITS SECRETION. Magnified 50 diameters.

The walls of the alveoli are lined by a single layer of epithelium which is columnar when the milk is being produced, but becomes flattened out as the secretion fills the alveoli. In fig. 395 milk globules may be seen forming within the columnar cells and also lying free within the alveoli. The contrast between alveoli distended with milk and those which have been emptied of the secretion is very striking (fig. 394). The emptying seems to be brought about by contraction of plain muscle-cells in the alveolus lying just inside the basement-membrane (as in the sweat glands): such contraction is readily brought about by intravenous injection of certain animal extracts (pituitary, corpus luteum). At the commencement of lactation large cells containing fat particles appear in the secretion (*colostrum corpuscles*). These are either detached portions of the secreting epithelium cells or, as some believe, emigrated leucocytes similar to the salivary corpuscles of saliva.

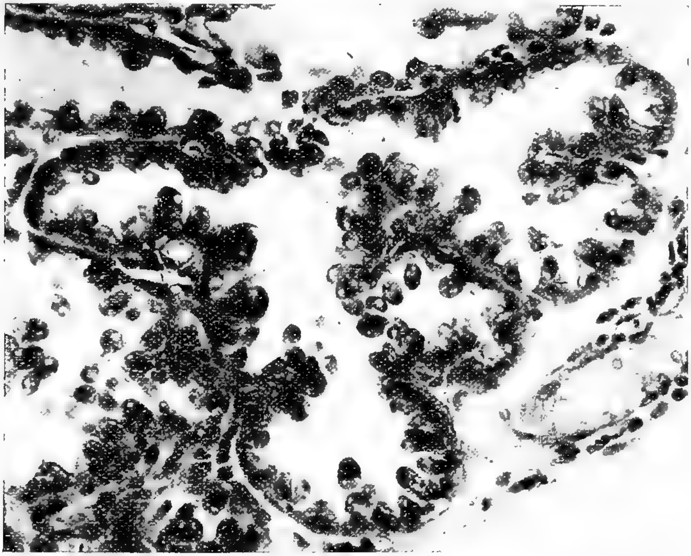

FIG. 395. -ALVEOLI OF MAMMARY GLAND OF LACTATING CAT. Photograph. Magnified 400 diameters.

Development.—The mammary glands are developed in the same manner as the sweat glands, excepting that the secreting part does not become convoluted and tubular. In the virgin mamma they show very few and small groups of alveoli, but as pregnancy advances the gland ducts bud out extensively, and many more alveoli are formed and undergo enlargement, until the greater part of the connective tissue in the mammary region is permeated by them. In sections of the lactating gland they may be seen in various stages of development. After lactation is over they undergo a process of retrogression.

LESSON XXVI.

STRUCTURE OF THE HEART.

1. In sections through the wall of the auricle note the relative thickness of the epicardium, myocardium, and endocardium. Observe the blood-vessels and nerve-fibres under the epicardium, often embedded in fat; here and there a ganglion may be seen under this membrane. Notice also the elastic networks under both the pericardium and endocardium. Make a general sketch of such a section.

2. In sections through the wall of the ventricle the same points are to be noticed. The muscular fibres are variously cut. In those which are cut longitudinally, the branching of the fibres and their union both laterally and by their branches may be seen. Notice also that although the fibres are cross-striated this is less distinct than in voluntary muscle, and that the nuclei lie near the centre of each fibre. Transverse markings may also be seen passing across the fibres between the nuclei; this is usually taken as indicating a division into cells. The endocardium is thin, especially over the columnæ carneæ.

3. Section through one of the valves of the heart.[1]

4. If a portion of endocardium of the sheep's heart is spread out on a slide and examined in salt solution, a network of large beaded fibres may be seen with a low power or even with a lens; they are also seen in sections. These are the fibres of Purkinje; they are formed of large, square-looking cells usually containing two nuclei, and having striated muscular substance at their periphery.

5. The lymphatics of the heart may be injected with Berlin blue by sticking the nozzle of the injecting syringe anywhere into the muscular substance, and forcing the fluid into the interstices. The commencing lymphatics which are thus injected lead to efferent vessels which pass under the epicardium towards the base of the heart.

6. The epithelium which covers the epicardium, and that which lines the endocardium, may be studied in preparations of the fresh organ which have been well rinsed with distilled water, then treated with nitrate of silver, again rinsed, and subsequently exposed to the light and hardened in alcohol. Surface sections are to be made and mounted in dammar.

Myocardium.—The muscular tissue of the heart (fig. 396) forms the main thickness of the ventricles and also of parts of the auricles. It is composed of a network of fibres which are formed of transversely striated cells, the structure of which has already been studied (Lesson XVII.).

In the interstices of the muscular bundles there is a considerable amount of areolar tissue in which run numerous blood-capillaries and lacunar lymphatics.

Epicardium.—The myocardium is covered externally by a layer of serous membrane—the epicardium or cardiac pericardium (fig. 397, A)—composed,

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[1] The appearances which are to be studied in sections 1, 2, and 3 can all be obtained in one preparation, viz. a vertical section including a portion of auricle and ventricle and a flap of the intervening auriculo-ventricular valve.

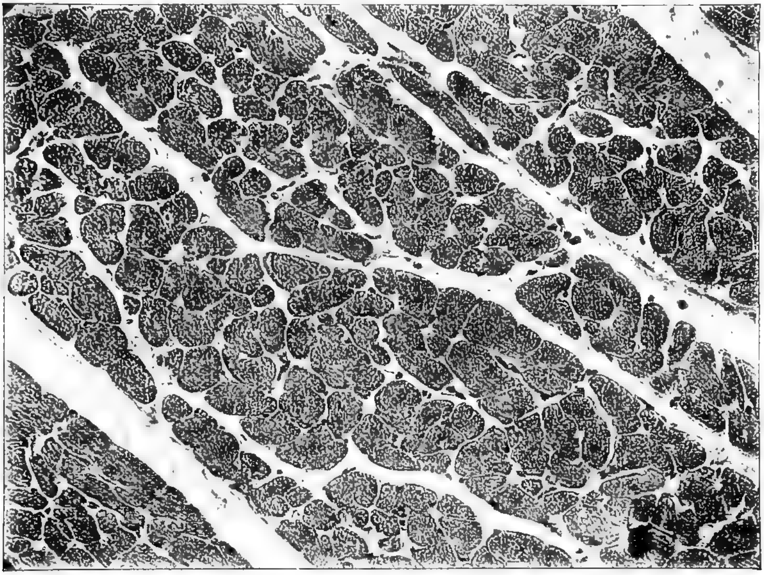
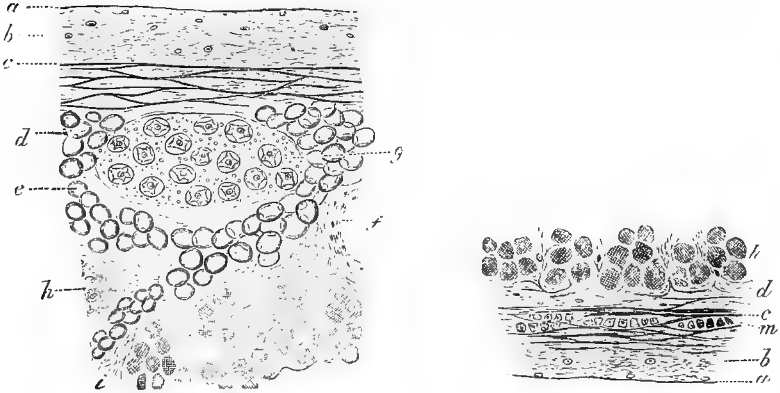


FIG. 396.—SECTION OF MYOCARDIUM. Magnified 200 diameters.

Most of the fibres are cut across. Notice the irregular outlines of the fibres and the manner in which they blend laterally with one another: the nuclei in the middle of the fibres: the interstitial connective tissue subdividing the muscular tissue into larger and smaller bundles.



A B

FIG. 397. SECTIONS OF THE RIGHT AURICLE.

A, Epicardium and adjacent part of the myocardium. *a*, serous epithelium in section; *b*, connective-tissue layer; *c*, elastic network; *d*, subserous areolar tissue; *e*, fat; *f*, section of a blood-vessel; *g*, a small ganglion; *h*, muscular fibres of the myocardium; *i*, intermuscular areolar tissue.

B, Endocardium and adjacent layer of the myocardium. *a*, lining epithelium; *b*, connective tissue with fine elastic fibres; *c*, layer with coarser elastic fibres; *d*, sub-endocardial connective tissue continuous with the intermuscular tissue of the myocardium; *h*, muscular fibres of the myocardium; *m*, plain muscular tissue in the endocardium.

like other serous membranes, of connective tissue and elastic fibres, the latter being most numerous in its deeper parts. Underneath the epicardium run the blood-vessels, nerves, and lymphatic vessels of the heart embedded in areolar and adipose tissue, this tissue being continuous with that which lies between the muscular bundles; the free surface of the membrane is covered by serous endothelium.

Endocardium.—The lining membrane of the cavities of the heart, known as the endocardium (fig. 397, B), has a structure not very unlike the pericardium. It is lined by a pavement-epithelium (endothelium), like that of a serous membrane, and consists of connective tissue with elastic fibres in its deeper part, between which there may, in some parts, be found a few plain muscular fibres. Fat is sometimes met with under the endocardium.

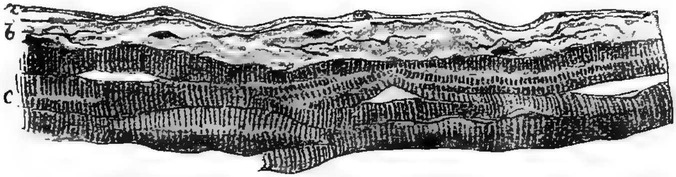


Fig. 398.—Endocardium covering one of the columnæ carneæ of the right ventricle. (Mann.)
a, endothelium; *b*, connective tissue with elastic fibres; *c*, muscular fibres of myocardium.

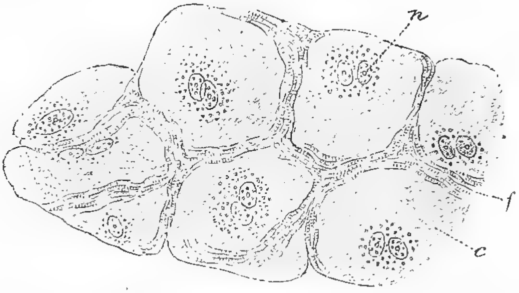


Fig. 399.—Fragment of the network of Purkinje's fibres from the ventricular endocardium of the sheep. (Ranvier.)
c, clear cell body; *n*, nuclei; *f*, striated fibrils.

In some animals, *e.g.* the sheep and ox, a network of large beaded trabeculæ occurs under the endocardium. They are formed of clear cells joined both end to end and laterally, and generally containing in their centre two nuclei, whilst the peripheral part of the cell is formed of cross-striated muscular tissue; the trabeculæ are known as the *fibres of Purkinje* (fig. 399). They are formed of cardiac cells which have undergone differentiation into striated muscle substance only at their periphery, the non-differentiated part of the cell having continued to grow until it has attained a considerable size. In man distinct fibres of Purkinje are not seen, but the innermost muscular fibres of the ventricles are larger than those which lie more externally: they also undergo development somewhat later (J. B. MacCallum).

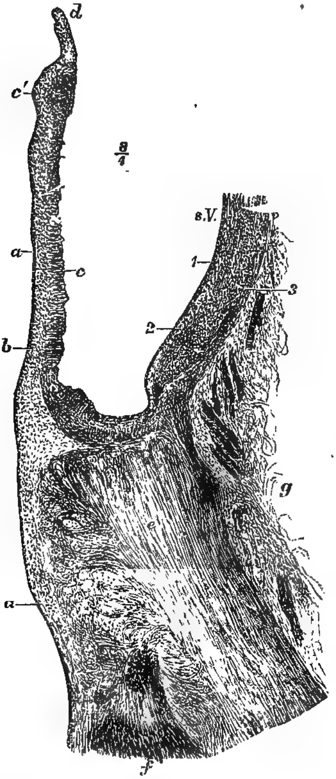


FIG. 400.—SECTION THROUGH ONE OF THE FLAPS OF THE AORTIC VALVE, AND PART OF THE CORRESPONDING SINUS OF VALSALVA, WITH THE ADJOINING PART OF THE VENTRICULAR WALL. (From a drawing by V. Horsley.)

a, endocardium, prolonged over the valve; *b*, subendocardial tissue; *c*, fibrous tissue of the valve, thickened at *c′* near the free edge; *d*, section of the lunula; *e*, section of the fibrous ring; *f*, muscular fibres of the ventricle attached to it; *g*, loose areolar tissue at the base of the ventricle; *s.V.*, sinus of Valsalva; 1, 2, 3, inner, middle, and outer coats of the aorta.

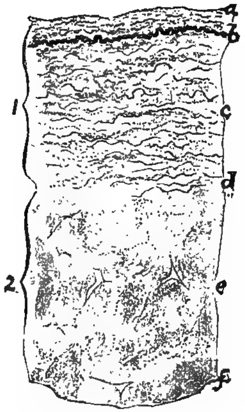


FIG. 401.—SECTION (LONGITUDINAL) OF AORTIC VALVE, HUMAN. (Mann.)

1. PART CONTINUOUS WITH ENDOCARDIUM.
2. PART CONTINUOUS WITH AORTIC WALL.

a, endothelium; *b*, elastic layer; *c*, fibrous layer with many elastic fibres; *d*, line of junction of ventricular and aortic portions; *e*, compact fibrous tissue with fine elastic fibres; *f*, endothelium and elastic lamina.

The auriculo-ventricular bundle.—Muscular fibres which show less differentiation than the rest of the cardiac muscle were first described by Stanley Kent as affording a bridging connexion between the muscle of the auricles and that of the ventricles. Such fibres are usually collected in man and mammals into a circumscribed fasciculus known as the *auriculo-ventricular bundle* (W. His, junr.), which extends from a plexiform mass known as the *node of Tawara* on the septal wall of the right auricle to the septum between the ventricles, where it bifurcates; a branch passing to each ventricle, over the inner surface of which it is continuous with a network of fibres which is represented in the sheep by Purkinje's fibres. The bundle and all its branches are invested by a special connective-tissue sheath which can be injected with coloured fluid: this affords the best means of demonstrating the whole system (Aagard). Besides the extension over the ventricles there is another prolongation of the same tissue in the right auricle, which ends or

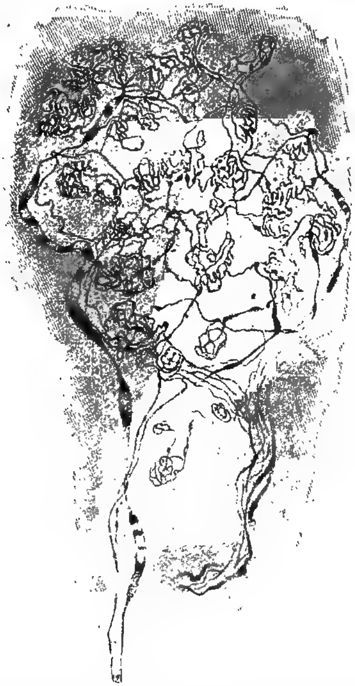


FIG. 402.—ENDING OF MEDULLATED NERVE-FIBRES, PROBABLY DERIVED FROM THE VAGUS, IN A SMALL CARDIAC GANGLION. (Dogiel.)

The ganglion-cells are not represented.

begins in another plexiform mass (*node of Keith and Flack*) which lies close to the entrance of the superior vena cava. The auriculo-ventricular bundle serves the purpose of propagating the contractions of the auricles to the ventricles and thus maintaining the regularity of rhythm of the ventricles; when the bundle is severed experimentally or by disease this propagation is no longer possible, and the ventricles then beat with a much slower rhythm than the auricles.

The **valves** of the heart are formed of folds of endocardium strengthened by fibrous tissue (figs. 400, 401). This tissue forms a thickening near the free edge of the valve (*c*′). At the base of the auriculo-ventricular valves the muscular tissue of the auricle may be found passing a short distance into the valves. In the fœtus these valves are at first almost entirely muscular.

The **nerves** of the heart are seen underneath the epicardium of both auricles and ventricles; in the former situation they are connected at intervals with small ganglia (fig. 397, A, *g*; figs. 402, 403, 404). The axons of the ganglion-cells pass to the muscular substance, and after dividing into fine fibrils, end in enlarged extremities, which are applied directly to the muscular fibres (fig. 287, p. 204). Other medullated nerve-fibres, which are probably afferent, terminate in complex ramifications in the endocardium (fig. 405) (Smirnow, A. S. Dogiel).

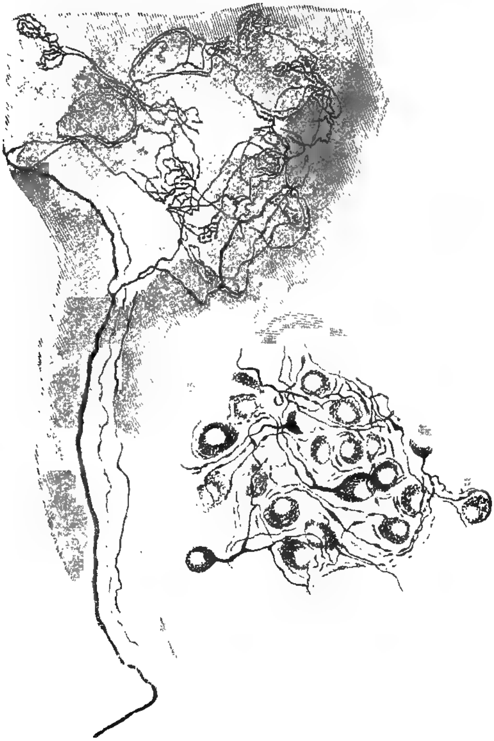


FIG. 403. FIG. 404.

FIG. 403.—ENDING OF NON-MEDULLATED NERVE-FIBRES (DERIVED FROM THE SYMPATHETIC) IN A SMALL GANGLION OF THE HEART. (Dogiel.)

The ganglion-cells are not represented.

FIG. 404.—A SMALL GANGLION FROM THE HEART, SHOWING THE GANGLION-CELLS AND THEIR PROCESSES. (Dogiel.)

The **blood-vessels** of the heart are very numerous. The veins are thin-walled, retaining the capillary structure (endothelium only) in vessels of as much as 0·25 mm. in diameter. The blood-vessels are accompanied by numerous **lymph-vessels**, which form plexuses under the cardiac pericardium and endocardium. The lymphatics of the myocardium occupy lacunar spaces in the interstitial connective tissue between the muscle-fibres and can be readily demonstrated by injecting coloured fluid into the substance of the myocardium; the fluid passes from these spaces into the vessels of the epi- and endo-cardium.

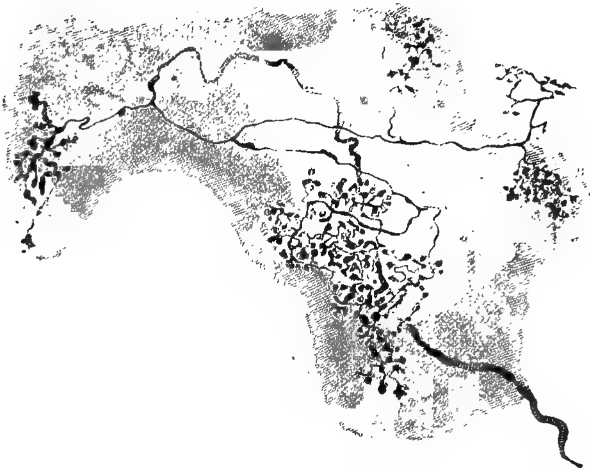


FIG. 405.—TERMINATION OF AN AFFERENT NERVE-FIBRE IN THE ENDOCARDIUM. (Dogiel.)

LESSON XXVII.

THE LARYNX, TRACHEA AND LUNGS.

1. In sections of the trachea and larynx, notice the epithelium, the basement-membrane (of some thickness in the human trachea and larynx), the lymphoid tissue of the mucous membrane, the elastic tissue external to this, and lastly, the fibrous membrane containing the cartilages. In the mucous membrane and sub-mucous areolar tissue look for sections of small mucous glands, ducts of which may be seen opening on the surface. At the back of the trachea notice the plain muscular fibres transversely arranged; there may be larger mucous glands external to these.

2. In sections of lung notice the alveoli collected into groups (infundibula or air-sacs). Find sections of bronchial tubes, some cut longitudinally and passing at their extremities into the alveolar passages, others cut across. In each tube notice the ciliated epithelium internally. Next to this the mucous membrane containing numerous elastic fibres and often thrown into folds; then the layer of circular muscular fibres, and, outside this, loose fibrous tissue in which in larger bronchial tubes pieces of cartilage may be seen embedded. Small mucous glands may also be observed in the fibrous tissue sending their ducts through the other layers to open on the inner surface. Notice that a branch of the pulmonary artery always accompanies a bronchial tube.

In the sections of the alveoli observe the capillary vessels passing from one side to the other of the intervening septa; and in places where the thin wall of an alveolus is seen flat in the section, the network of blood-capillaries upon it. In sections stained with orcein the elastic fibres are displayed. Within the alveoli nucleated corpuscles may here and there be seen with dark particles in their protoplasm. They are phagocytes which have migrated from the blood-vessels and lymphatics, and have taken in inhaled particles of carbon. They may pass back into the lung tissue, for similar cells are seen in this. Make a sketch of part of the wall of one or more bronchial tubes and of one or two of the alveoli.

3. The shape and arrangement of the alveoli is best seen in casts, which can be squeezed out of slices of a lung which has been moderately distended with coloured gelatine.

4. In sections of a fresh lung the air-cells of which have been filled with a mixture of gelatine and nitrate of silver solution the epithelium of the alveoli can be studied. The sections are made with the freezing microtome, and mounted in glycerine, which should be warmed after the cover-glass is applied in order to melt the gelatine.

5. Mount a section of lung in which the pulmonary vessels have been injected. Study the general arrangement of the vessels with a low power, and the network of capillaries of the alveoli with a high power. Observe that the veins run apart from the arteries. Sketch the capillary network of one or two adjoining alveoli.

THE TRACHEA AND LARYNX.

The **trachea** or wind-pipe is a fibrous and muscular tube, the wall of which is rendered somewhat rigid by C-shaped hoops of cartilage which are embedded in the fibrous tissue. The muscular tissue, which is of the plain variety, forms a flat band, the fibres of which run transversely at the back of the tube. Both larynx and trachea are lined by a *mucous membrane* (figs. 406, 407), which has ciliated epithelium upon its inner surface. The epithelium-cells, which have been already described (Lesson VIII.), have goblet-cells amongst them; they rest upon a thick basement-membrane. The corium of the mucous membrane consists of areolar and lymphoid tissue, and contains numerous blood-vessels and lymphatics. In its deepest part is a well-marked layer of longitudinal elastic fibres. Many small glands—mucous and mixed mucous and serous—are found in the wall of the trachea. They may lie either within the mucous membrane or in the submucous areolar tissue, or, lastly, at the back of the trachea, outside the transverse muscular fibres.

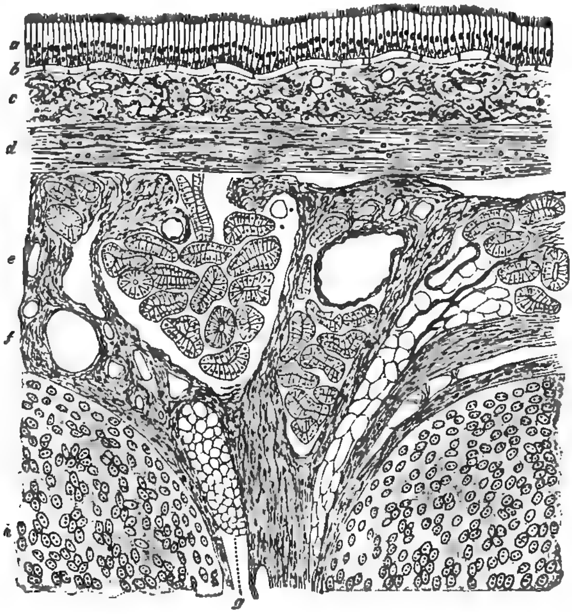


FIG. 406.—LONGITUDINAL SECTION OF THE HUMAN TRACHEA, INCLUDING PORTIONS OF TWO CARTILAGINOUS RINGS. (Klein.) Moderately magnified.

a, ciliated epithelium; *b*, basement-membrane; *c*, superficial part of the mucous membrane, containing the sections of numerous capillary blood-vessels and much lymphoid tissue; *d*, deeper part of the mucous membrane, consisting mainly of elastic fibres; *e*, submucous areolar tissue, containing the larger blood-vessels, small mucous glands (their ducts and alveoli are seen in section), fat, etc.; *f*, fibrous tissue investing and uniting the cartilages; *g*, a small mass of adipose tissue in the fibrous layer; *h*, cartilage.

The two main divisions of the trachea, the right and left *bronchi*, are precisely similar in structure to the main tube.

The **larynx** resembles the trachea so far as the structure of the mucous membrane is concerned. It also is lined by ciliated epithelium, but over the true vocal cords and upon the epiglottis, as well as here and there in the part above the glottis, stratified epithelium is found; and taste-buds

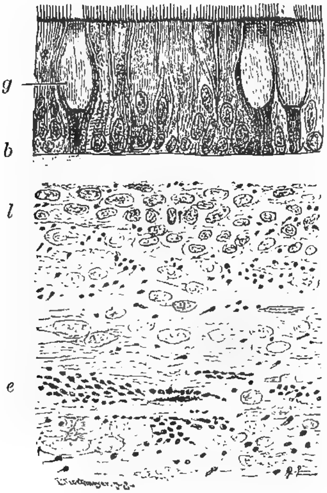


FIG. 407.—MUCOUS MEMBRANE OF LARYNX. (Merkel.)

g, a goblet-cell amongst the ciliated epithelium-cells; *b*, basement-membrane; *l*, lymphoid tissue; *e*, elastic fibres, cut across.

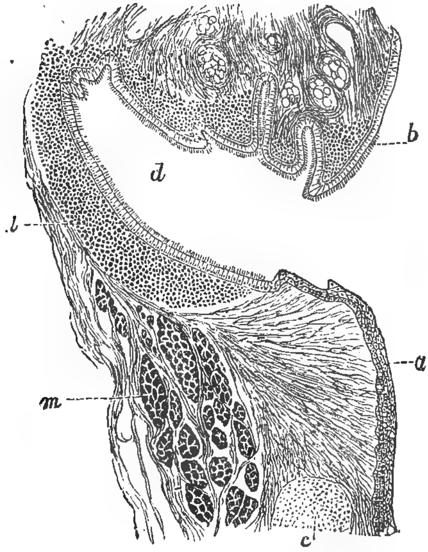


FIG. 408.—LONGITUDINAL SECTION THROUGH THE VENTRICLE OF THE LARYNX OF A CHILD. (Klein.)

a, true vocal cord; *b*, false vocal cord; *c*, nodule of cartilage; *d*, ventricle of Morgagni; *l*, lymphoid tissue; *m*, thyro-arytenoid muscle.

may occur in this epithelium, except over the vocal cords. Numerous nerves end in the epithelium.

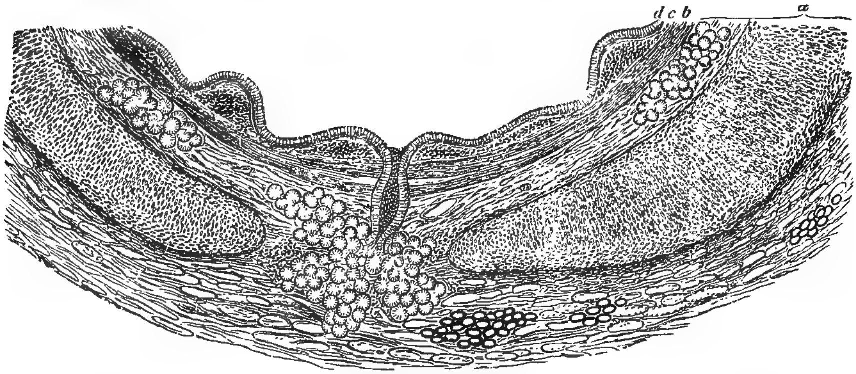


FIG. 409.—PORTION OF A TRANSVERSE SECTION OF A BRONCHIAL TUBE, HUMAN, 6 MM. IN DIAMETER. (F. E. Schultze.) Magnified 30 diameters.

a, cartilage and fibrous layer with mucous glands, and, in the outer part, a little fat; in the middle, the duct of a gland opens on the inner surface of the tube; *b*, annular layer of involuntary muscular fibres; *c*, elastic layer, the elastic fibres in bundles which are seen cut across; *d*, columnar ciliated epithelium.

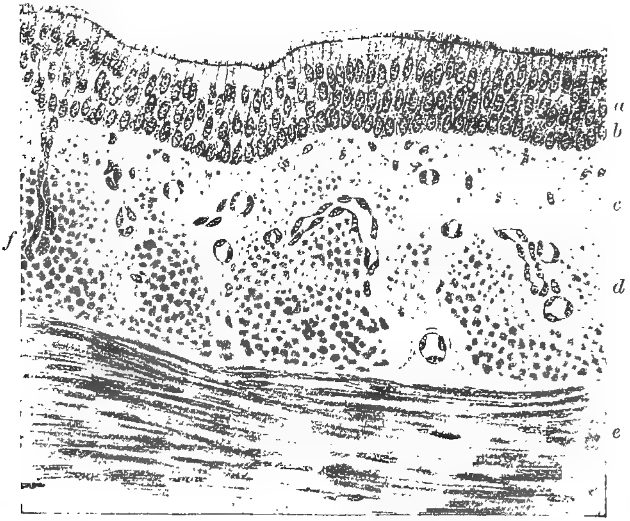


FIG. 410.—SECTION OF PART OF A BRONCHIAL TUBE. Magnified 200 diameters.

a, ciliated epithelium; *b*, basement-membrane; *c*, superficial part of mucous membrane, with fine elastic fibres; *d*, deeper part with numerous coarser fibres; *e*, plain muscle of bronchus; *f*, duct of gland passing through mucous membrane.

The true vocal cords are composed of fine elastic fibres.

Lymphoid tissue is especially abundant in the mucous membrane of the ventricle of Morgagni (fig. 408, *d*). A large number of mucous glands open into this cavity and into that of the sacculus which communicates with it.

The cartilages of the trachea and the thyroid, cricoid, and arytenoid cartilages of the larynx are hyaline; all these are liable to ossify as age advances. The epiglottis and the cartilages of Santorini and of Wrisberg are composed of elastic fibro-cartilage. This is also the case with the uppermost part of the arytenoid and the tip of the vocal process of the same cartilage.

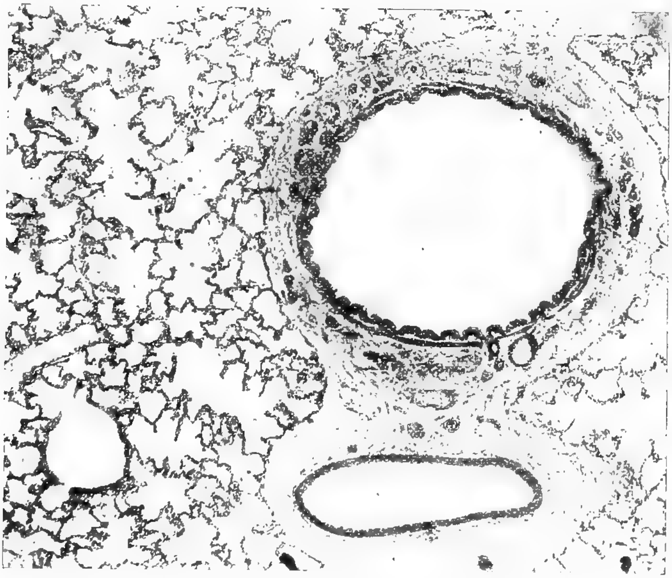


FIG. 411.—SECTION OF LUNG, DOG, SHOWING A MODERATE SIZED BRONCHIAL TUBE WITH THE BRANCH OF THE PULMONARY ARTERY ACCOMPANYING IT. Photograph. Magnified 50 diameters.

Some of the adjacent pulmonary tissue is included in the section. On the left is seen the section of an alveolar bronchial tube.

THE LUNGS.

The lungs are formed by the ramifications of the *bronchial tubes* and their terminal expansions which form groups or lobules of sacculated dilatations (*air-sacs, infundibula*), beset everywhere with small irregularly hemispherical bulgings, known as the *pulmonary alveoli* or *air-cells.*

The **bronchial tubes** (figs. 409 to 413) are lined (except the terminal bronchi) by ciliated epithelium which rests on a basement-membrane. External to this is the corium of the mucous membrane, containing a large number of longitudinal elastic fibres and some lymphoid tissue. Outside this again is a complete layer of plain muscular fibres encircling the tube. Next comes a loose fibrous layer in which, in the large and medium sized tubes (figs 409, 412), small plates of cartilage are embedded. Mucous glands are also present in this tissue.

The extremities of the small bronchial tubes expand into passages, *respiratory bronchioles*, which give off as branches the *alveolar passages.* The walls of both these are beset with alveoli. The alveolar passages lead into irregularly spherical alveolated dilatations (*atria*) with which a number of blind and often funnel-shaped diverticula completely covered with alveoli communicate; these are the *infundibula* or *air-sacs* (Waters). The arrangement of the parts, according to the investigations of W. S. Miller, is as follows: Two or more *air-sacs*, or groups of *alveoli*, open from a common chamber (*atrium*), and three to six atria are connected with the ending of an alveolar passage. The latter lead out of the *respiratory bronchioles*, which are expanded continuations of the smallest bronchial tubes.

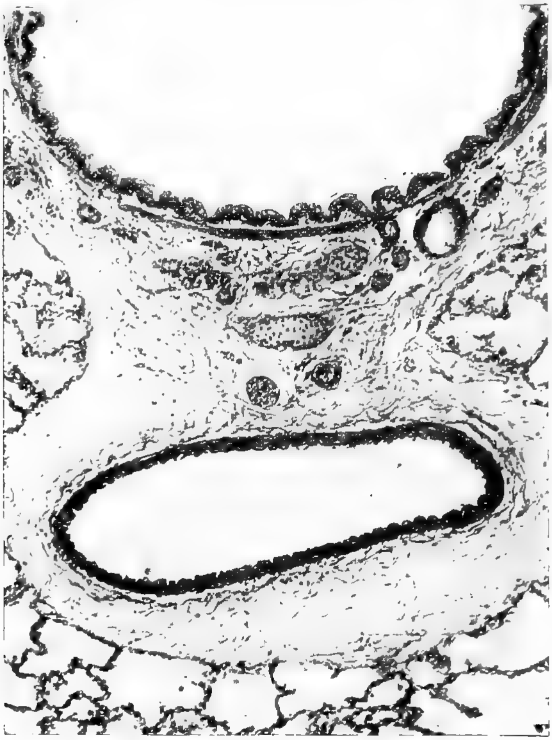


FIG. 412.—PART OF THE SECTION SHOWN IN THE PRECEDING FIGURE MAGNIFIED 200 DIAMETERS.

In the bronchial tube, the epithelium, the circular muscular fibres, parts of mucous glands and two small pieces of cartilage can be seen. The corrugations of the mucous membrane are caused by post-mortem contraction of the circular muscle.

The epithelium changes in character as we trace the small bronchi into the respiratory bronchioles; from columnar and ciliated it becomes cubical and non-ciliated, and there are patches of the respiratory epithelium (see below) not only in the alveoli which occur scattered over the respiratory bronchioles but also elsewhere in the wall of the latter. The plain muscular tissue of the small bronchi is continued as a distinct layer on the walls of the respiratory bronchioles, but not on those of the alveolar passages and atria, although some muscle cells occur round the mouths of the atria and even of the alveoli.

The **alveoli** are lined by large, irregular flattened cells (fig. 416), which form an extremely delicate layer (*respiratory epithelium*), separating the blood-capillaries from the air within the alveoli. Amongst the flattened cells are here and there groups of smaller and thicker (cubical) epithelium cells. The capillary network of the alveoli is very close (fig. 417), and the capillary vessels of adjoining alveoli are in complete continuity, the vessels passing first to one side and then to the other of the septa which separate the adjacent alveoli. Outside the epithelium a thin layer of connective tissue (basement-membrane?) forms the wall of each alveolus. Elastic fibres are numerous around the mouths of the alveoli, and a certain number course over the wall of each alveolus (fig. 418).

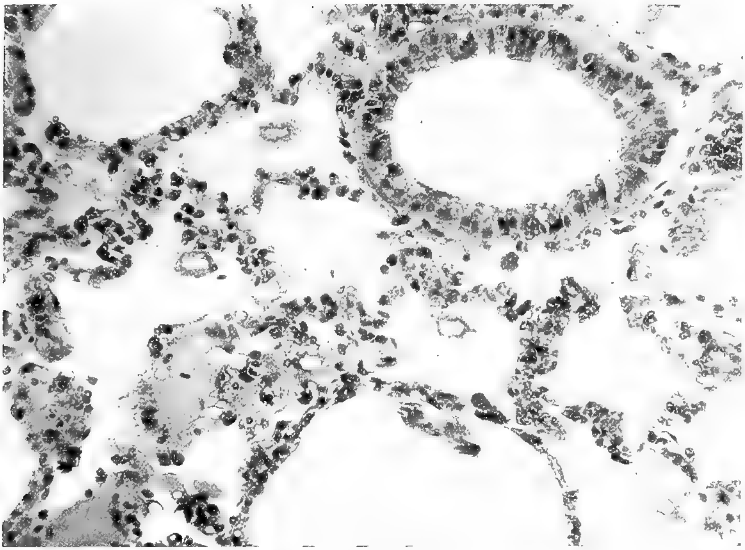


FIG. 413.—SECTION OF A SMALL BRONCHIAL TUBE AND ADJOINING ALVEOLI, RABBIT. × 300.

Blood-vessels.—Branches of the pulmonary artery accompany the bronchial tubes to be distributed to the capillary networks upon the alveoli; from these networks the blood is returned by the pulmonary veins. An arteriole runs with each terminal bronchiole, and, dividing into as many branches as there are atria (fig. 415), is distributed to the capillary networks of all the air-cells with which the bronchiole is connected (Miller). From these networks one or two venules collect the blood, usually coursing (independently of the arteriole) on the outer border of the group of infundibula, and unite with other venules to form efferent veins. The venules of the super-

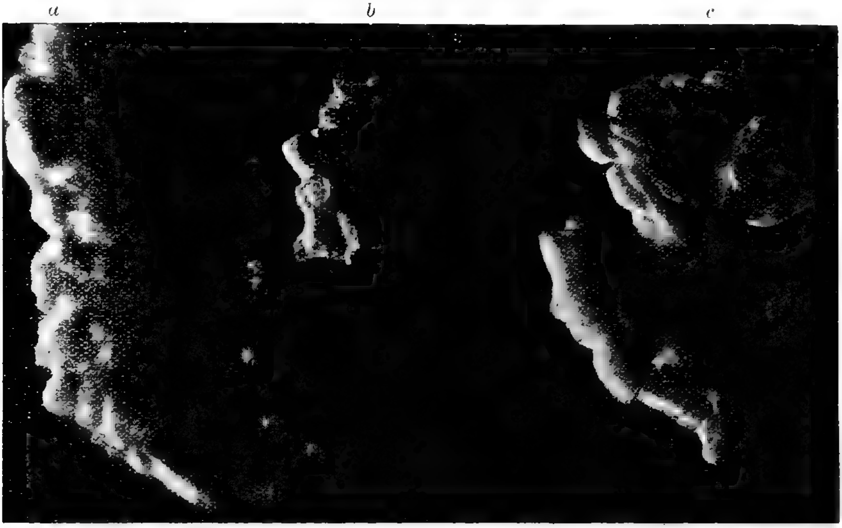


FIG. 414.—GELATINE CASTS FROM LUNG OF YOUNG CAT. PHOTOGRAPHED BY REFLECTED LIGHT. Magnified 75 diameters.

The figure shows (from left to right); (*a*) a respiratory bronchiola, its wall partly beset with alveoli; (*b*) part of a terminal group of alveoli; (*c*) two or three terminal groups of alveoli (infundibula or air-sacs), still connected with their common atrium.

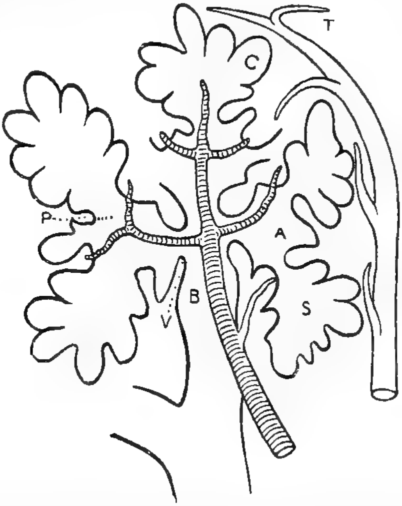


FIG. 415.—DIAGRAM OF THE ENDING OF A BRONCHIAL TUBE. (W. S. Miller.)

B, terminal bronchiole; *V*, vestibule; *A*, atrium; *S*, air-sac or infundibulum; *C*, air-cell or alveolus; *P*, ending of pulmonary arteriole; *T*, commencement of pulmonary venule.

ficial lobules are connected with a vascular network at the surface of the lung underneath the pleura. This network is also supplied from the bronchial arteries. The veins, pursuing a separate course through the tissue of the lung, join with others to form larger vessels which pass to the root of

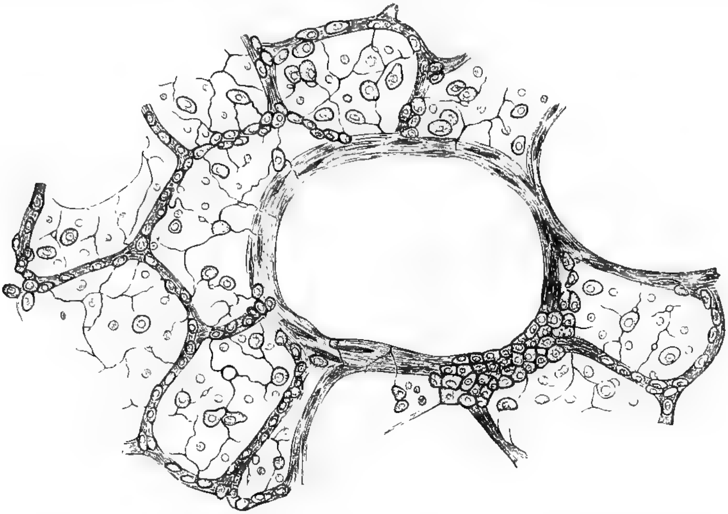


FIG. 416.—SECTION OF PART OF CAT'S LUNG, STAINED WITH NITRATE OF SILVER. (Klein.) Highly magnified.

Both the cubical and the large flattened cells of the alveoli are shown. In the middle is a section of a small bronchial tube, with a patch of cubical epithelium-cells at one side.

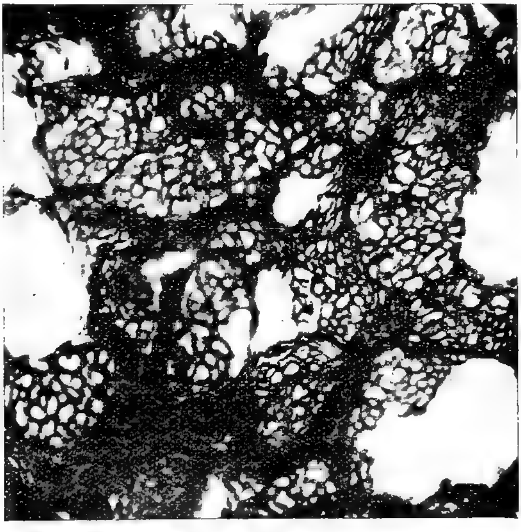


FIG. 417.—SECTION OF INJECTED LUNG, HUMAN, INCLUDING SEVERAL CONTIGUOUS ALVEOLI. Magnified 300 diameters.

the lung. Branches from the bronchial arteries are distributed to the walls of the bronchial tubes, and to the connective tissue of the lung, including that of the pleura. Bronchial veins accompany the bronchial arteries to the larger tubes, but most of the blood brought to the lungs by the bronchial arteries is returned by the pulmonary veins. Connective tissue intervenes everywhere in small quantity between the infundibula (interstitial tissue), and forms a distinct layer, containing much elastic tissue, covering the surface of the lung underneath the serous membrane (subserous tissue). In some animals (*e.g.* guinea-pig) the subserous layer contains plain muscular tissue, which is especially developed near the lung-apex ; it has not been detected in man.

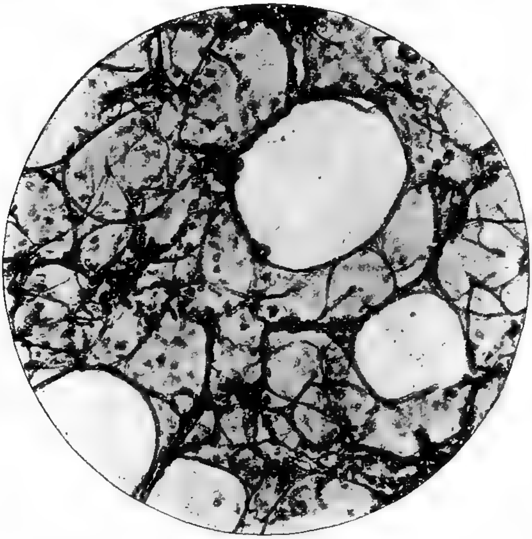


FIG. 418.—ELASTIC FIBRES OF LUNG, STAINED WITH ORCEIN. Magnified 200 diameters.

The **lymphatics** of the lung accompany the bronchial tubes, the branches of the pulmonary artery, and the branches of the pulmonary vein ; they also form a network in the pleura. The atria and air-sacs have no lymphatics in their walls (Miller). The bronchial lymphatics are less superficial than the corresponding blood-vessels. The larger tubes have two plexuses ; one within, the other outside the cartilages. The smaller have only one set. The lymphatics of the bronchi are connected with those of the arteries and veins by lateral branches curving off at the divarications of the tubes ; at these points there is usually an accumulation of lymphoid tissue. The larger arteries and veins have two accompanying lymphatics, the smaller only one. All the lymphatics tend towards the hilus, and enter lymphatic glands at the root of the lung. Those in the pleura have been said to communicate, by means of stomata between the epithelial-cells of the serous membrane, with the cavity of the pleura; this connexion is denied by Miller. The lymphatics of the pleura are furnished with numerous valves.

The **pleura** which covers the surface of the lung has the usual structure of a serous membrane (fig. 325, p. 229). As already mentioned, it is provided with a special network of blood-vessels, supplied partly from the pulmonary vessels of the superficial lobules, partly from the bronchial arteries.

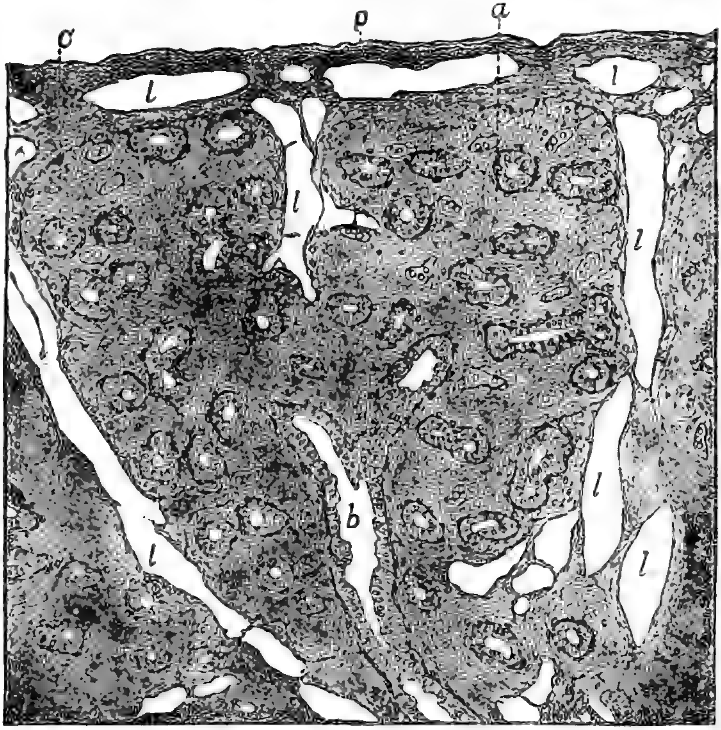


Fig. 419. Section of developing lung (pig) showing the gland-like character of the growing bronchial tubes and alveoli. (J. M. Flint.) Magnified 70 diameters.

a, interstitial embryonic connective tissue; *b*, bronchial tube; *c*, alveoli; *l*, lymph-clefts; *p*, pleura.

The lung is developed in the same manner as a secreting gland (fig. 419), to which, up to a certain period of formation, it bears a close resemblance. Its alveoli correspond with the secreting alveoli of a racemose gland, and the cells which line them are, prior to the introduction of air, of some thickness and of protoplasmic nature. It is only after the organ has come into use for respiration that they acquire the thin, flattened scaly appearance which most of them present in the adult lung.

LESSON XXVIII.

STRUCTURE AND DEVELOPMENT OF THE TEETH.

1. Study first with the low power and afterwards with the high power a longitudinal section of a human tooth which has been prepared by grinding. It is better to purchase this specimen, for the process of preparation is difficult and

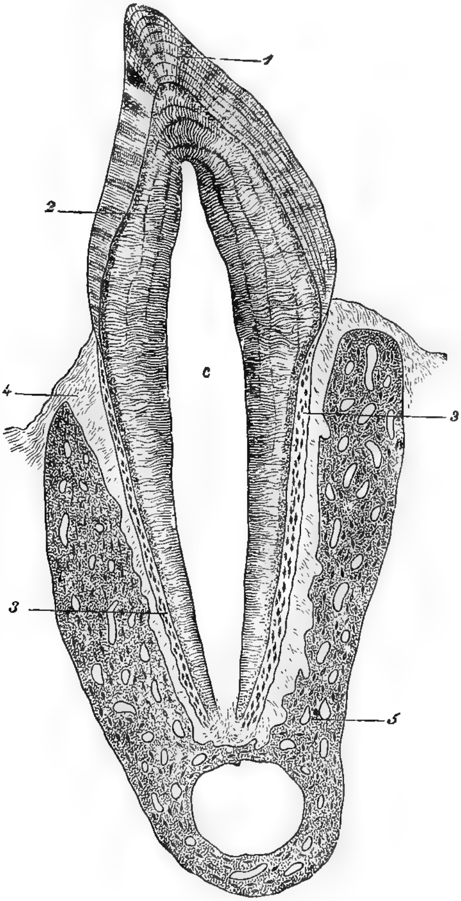


Fig. 420.—Vertical section of a tooth in situ. (Waldeyer.)

c is placed in the pulp-cavity, opposite the cervix or neck of the tooth; the part above is the crown, that below is the root (fang). *1*, enamel with radial and concentric markings; *2*, dentine with tubules and incremental lines; *3*, cement or crusta petrosa, with bone corpuscles; *4*, dental periosteum; *5*, bone of lower jaw.

tedious without the aid of special apparatus. Examine carefully the enamel, the dentine, and the cement. The dark appearance of the dentinal tubules is due to

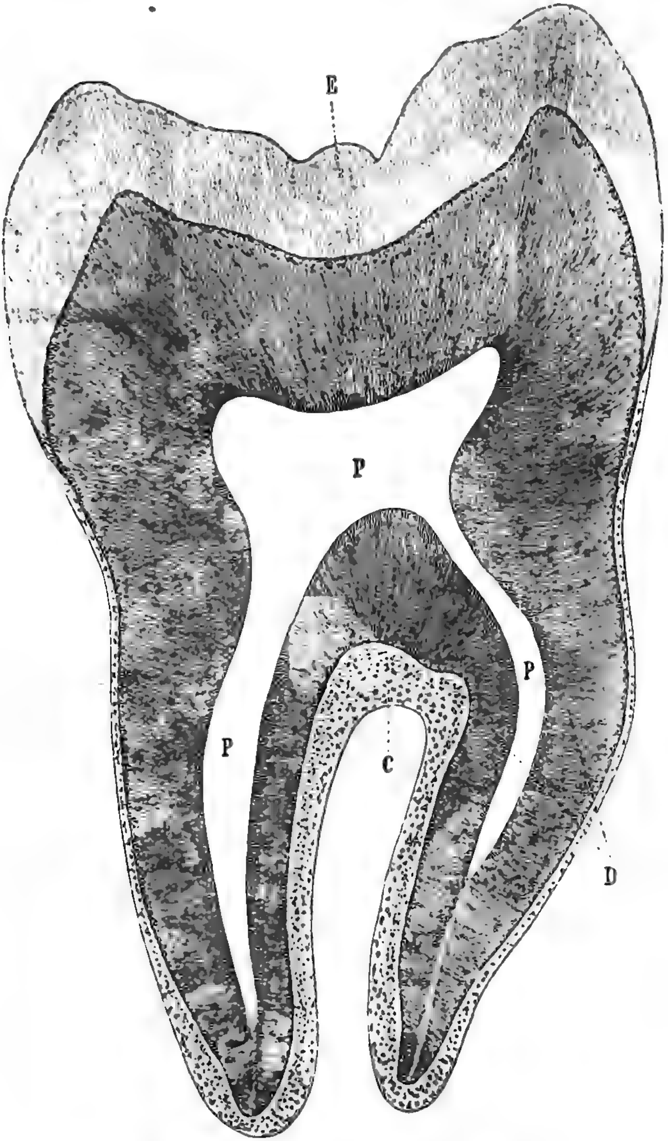


FIG. 421.—SECTION OF MOLAR TOOTH. (Sobotta.) × 8.
E, enamel; *D*, dentine; *C*, cement; *P*, pulp-cavity.

their containing air in the dried specimen. Measure the diameter of the enamel prisms and of some of the dentinal tubules. Make sketches from each of the tissues.

2. Section of a tooth *in situ*, which has been decalcified after fixation, and stained. In this section the mode of implantation of a tooth, as well as the structure of the pulp, can be made out. Make a general sketch under a low power, and under a high power draw a small piece of the pulp showing the processes of the odontoblasts extending into the dentinal tubules.

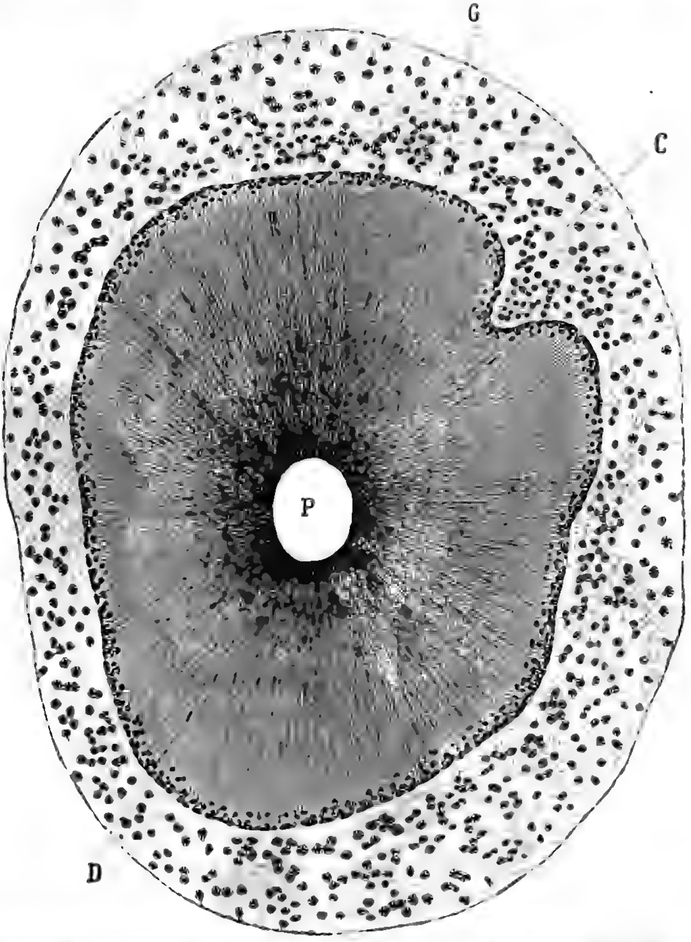


FIG. 422.—CROSS-SECTION OF ROOT OF CANINE TOOTH, HUMAN. (Sobotta.) × 25.
D, dentine; *G*, its granular layer; *C*, cement; *P*, pulp-cavity.

3. The development of the teeth and the formation of their tissues are studied in sections made across the snout and lower jaw of fœtal and young animals. The preparations may be stained in bulk or the individual sections may be stained.

STRUCTURE OF THE TEETH.

A **tooth** consists in man of three calcified tissues: *enamel*, which is of epithelial origin, *dentine*, and *cement* or *crusta petrosa*. The dentine forms the main substance of a tooth, the enamel covers the crown, and the cement is a layer of bone which invests the root (figs. 420 to 422).

Enamel is formed of elongated hexagonal *prisms* (figs. 423, 424), which are set vertically, or with a slight curvature, upon the surface of the dentine. They are marked at tolerably regular intervals with slight transverse shadings producing an indistinct cross-striated appearance (fig. 425). Sometimes coloured lines run through the enamel across the direction of its prisms. The enamel prisms have when first laid down a fibrous structure, but this becomes obscured after their calcification is complete, although it can occasionally be made out (fig. 425). C. Tomes has shown that the enamel of the fully formed tooth contains only an extremely minute proportion of animal matter: practically it is wholly composed of earthy matter (lime salts).

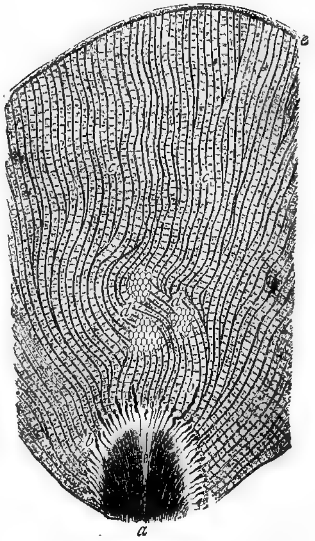


FIG. 423.—SECTION THROUGH THE ENAMEL OF A TOOTH. Magnified 200 diameters. (Rauber.)

a, projection of dentine, showing some of its tubules, *b*, penetrating into the enamel; *c*, *c*, enamel fibres cut longitudinally; *d*, *d*, prisms cut transversely; *e*, cuticle of the enamel.

The enamel of unworn teeth is covered by a very thin membrane of a horny nature. This membrane appears to be the remains of the layer of cells which produced the enamel. It is known as *Nasmyth's membrane* or the *cuticle of the enamel.*

Dentine is constituted of a hard dense substance like bone, but containing no Haversian canals or lacunæ. It is pierced everywhere by fine canaliculi (*dentinal tubules*, fig. 426), radiating outwards from a central cavity which, during life, contains the pulp. The tubules branch at acute angles as they pass outwards; the resulting tubules become gradually finer towards the periphery of the dentine. The main tubules give off along the whole course very numerous lateral branches which extend for a considerable distance in the dentine, and as they proceed become of almost immeasurable fineness (Mummery). To exhibit these fine ramuscles special methods of staining are required.

The tubules have a proper wall of their own, which can be isolated by steeping a section of tooth in strong hydrochloric acid. In the living tooth they are occupied by protoplasmic fibres (Tomes' fibres), which are prolonged from the superficial cells (odontoblasts) of the pulp.

The intertubular substance appears for the most part homogeneous, but it can be shown to have a fibrous structure (see next page). Indications of

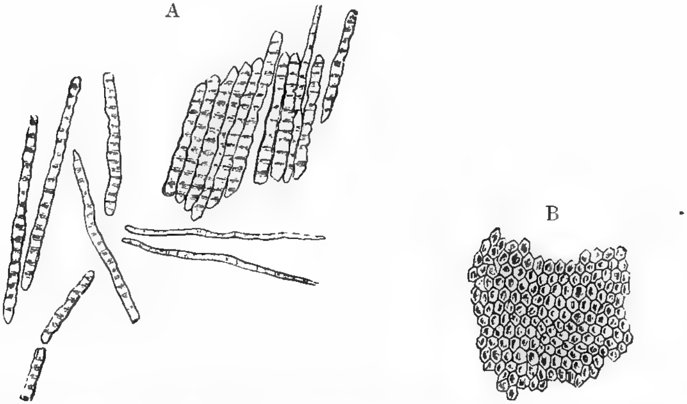


FIG. 424.—ENAMEL PRISMS. Magnified 350 diameters. (Kölliker.)
A, Fragments and single fibres of enamel, isolated by the action of hydrochloric acid.
B, Surface of a small fragment of enamel, showing the hexagonal ends of the fibres.

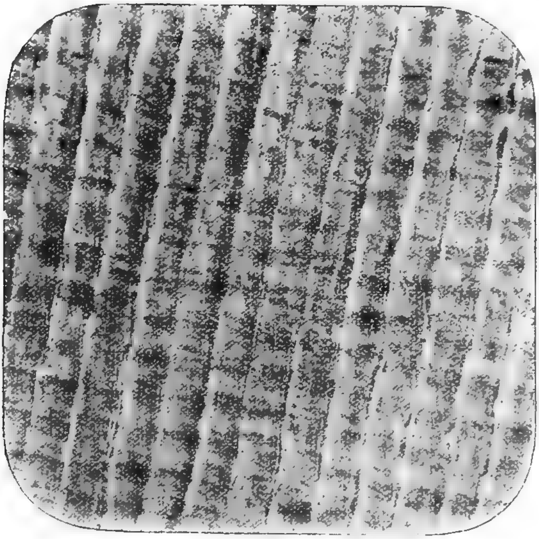


FIG. 425.—SECTION OF ENAMEL TAKEN ALONG THE DIRECTION OF THE PRISMS. Magnified about 900 diameters. (From a preparation by Leon Williams.)
The prisms show both a cross-striated appearance and a longitudinal fibrillation.

the fact that its calcareous matter was deposited in the form of globules can be seen in various parts. This is particularly the case in places where the globular deposit was imperfect; the spaces (*interglobular spaces*) left between the globules then produce the appearance of irregular cavities in sections of macerated tooth prepared by grinding and mounted dry. Under these conditions the cavities are occupied by air only, for the uncalcified animal matter has been destroyed in the process of maceration. Such interglobular spaces are most common near the surface of the dentine immediately within the crusta petrosa where they give a granular effect to the section (*granular layer*, fig. 426, 2, and fig. 422, G). But they are also well seen in the course of certain lines or clefts which are seen traversing the dentine across the direction of the tubules (*incremental lines*, fig. 420, one such shown magnified in fig. 428). After decalcification the dentine can be separated into lamellæ along these incremental lines.

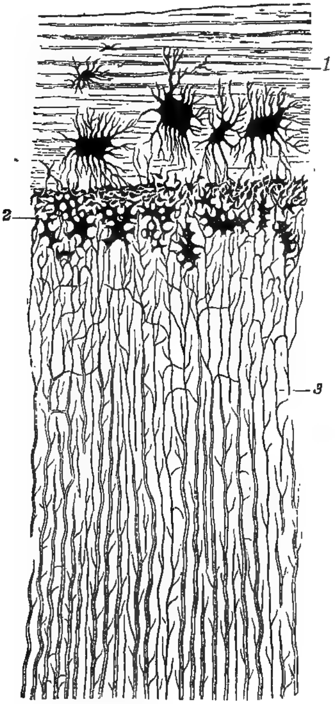


FIG. 426.

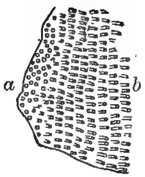


FIG. 427.

FIG. 426.—SECTION OF FANG OF TOOTH, PARALLEL TO DENTINAL TUBULES. Magnified 300 diameters. (Waldeyer.)

1, cement, with large bone lacunæ and indications of lamellæ; *2*, granular layer of Purkinje (interglobular spaces); *3*, dentinal tubules.

FIG. 427.—SECTION ACROSS DENTINAL TUBULES. Magnified 300 diameters. (Fraenckel.)

a, cut across; *b*, cut obliquely.

The animal matter of dentine resembles bone and the connective tissues generally in having its ground-substance pervaded by fibres which yield gelatine on boiling. These fibres, which have been especially investigated by v. Ebner and Howard Mummery, are difficult of demonstration in the fully calcified dentine; but in developing dentine and in dentine which is attacked by caries, they are more easily shown. They run for the most part parallel to the surface.

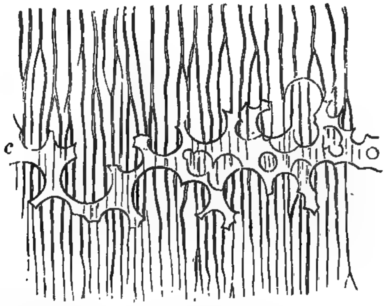


FIG. 428.—A SMALL PORTION OF DENTINE WITH INTERGLOBULAR SPACES. Magnified 350 diameters. (Kölliker.)

c, portion of incremental line formed by the interglobular spaces, which are here filled up by the transparent mounting material.

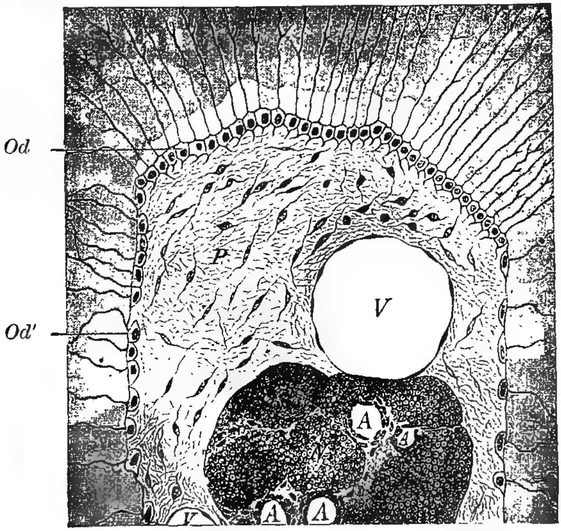


FIG. 429.—SECTION ACROSS THE ROOT OF A YOUNG TOOTH SHOWING THE PULP IN SITU. (Röse.)

P, pulp; *V*, *V*, veins; *A*, *A*, *A*, arterioles; *N*, nerve bundles; *Od*, columnar odontoblasts still depositing dentine; *Od'*, flattened odontoblasts which have ceased to form dentine.

The **pulp** (fig. 429) consists of a soft, somewhat jelly-like, connective tissue, containing many branched cells, a network of blood-vessels, and many nerve-fibres, for the most part medullated but some non-medullated, which pass into the pulp-cavity along with the blood-vessels by a minute canal at the apex of the fang. The superficial cells of the pulp form an almost continuous layer, like an epithelium (fig. 429, *Od*, *Od'*). They are known as *odontoblasts*, from having been concerned in the formation of the dentine. The nerve-fibres form a plexus near the bases of the odontoblasts, and from this plexus numerous fibrils pass to the dentine and, as Mummery has shown, enter the dentinal tubules along with the processes of the odontoblasts (fig. 430), and pass along the tubules in all probability for the greater part of their extent.

As age advances nodules of dentine may be formed in the interior of the pulp. Such nodules sometimes enclose blood-vessels, and thus give to this secondary dentine an appearance resembling bone. It has been on that account termed *osteodentine*.

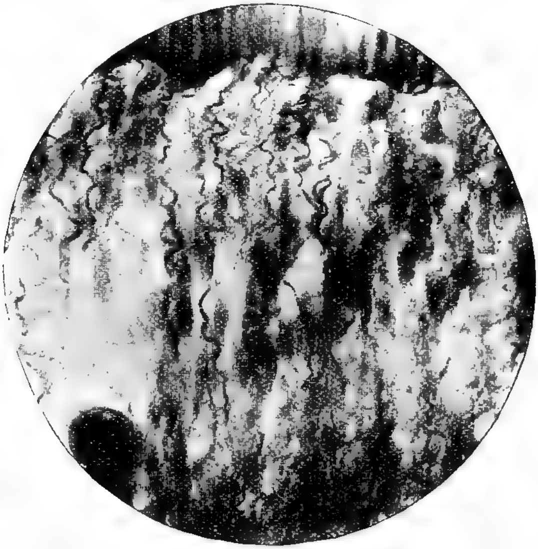


FIG. 430.—PREPARATION OF TOOTH STAINED BY A MODIFIED GOLD METHOD SHOWING NERVE-FIBRILS ENTERING THE DENTINE. (J. Howard Mummery.)

The **crusta petrosa** or **cement** (figs. 422, 426) is a layer of lamellated bone, including lacunæ and canaliculi, but without Haversian canals in normal human teeth. It is covered with periosteum (*dental periosteum*), which also lines the socket. The fibrous bundles of this periosteum extend on the one side into the crusta petrosa, on the other into the bony wall of the socket for the tooth, and thus serve to fix the tooth very securely.

DEVELOPMENT OF THE TEETH.

The development of the teeth has a general similarity to that of the hairs. The first change which foreshadows their development takes the form of a continuous thickening of the epithelium along the line of the gum; this thickening grows into the corium of the mucous membrane to form the

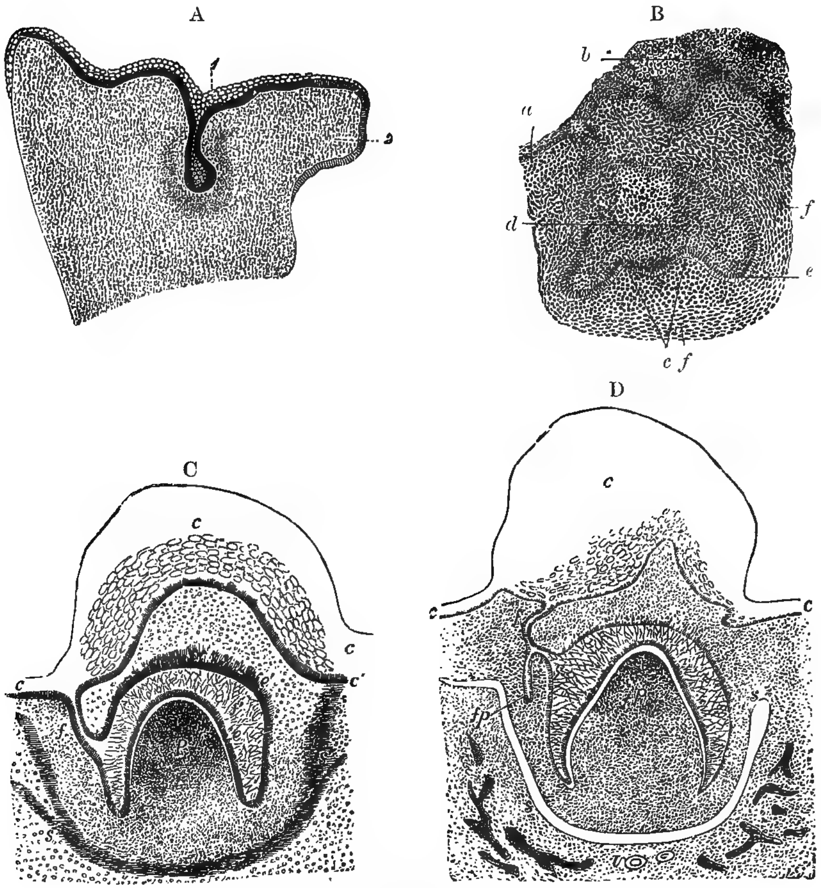


Fig. 431.

A. Section across the upper jaw of a fœtal sheep, 3 cm. long. (Waldeyer.)

1, common dental lamina dipping down into the mucous membrane where it is half surrounded by a horseshoe-shaped more dense-looking tissue, the germ of the dentine and dental sac; *2*, palatine process of the maxilla.

B. Section from fœtal calf similar to that shown in *A*, but passing through one of the special dental germs, here becoming flask-shaped. (Röse.)

a, epithelium of mouth, thickened at *b*, above special dental germ; *c*, papilla; *d*, special dental germ; *e*, enamel epithelium; *f*, dental sac.

C and *D.* Sections at later stages than *A* and *B*, the papilla having become formed and having become partly surrounded by the epithelial germ. (Kölliker.)

c, epithelium of gum, sketched in outline; *f*, neck of dental germ; *f'*, enamel organ; *e*, its deeper columnar cells; *e'*, projections into the corium; *p*, papilla; *s*, dental sac forming. In *D*, the dental germ (*fp*) of the corresponding permanent tooth is seen.

common dental germ or *lamina*, fig. 431, A. At regular intervals there is a further thickening and growth from the common germ into the tissue of the mucous membrane, each of these special rudiments, which are ten in number, swelling out below into a flask-shaped mass of cells, the *special* *dental germ* (fig. 431, B) of a milk-tooth. The intermediate parts of the dental lamina long remain, forming a common epithelial strand uniting the several special dental germs to one another, and to the epithelium covering the gum (fig. 431, C, D, *f*). A vascular *papilla* is continued from the corium into the bottom of each special germ (fig. 431, C, D, *p*); this papilla has the shape of the crown of the future tooth. Each special dental germ, with its included papilla, presently becomes almost entirely cut off from the epithelium of the mouth, and surrounded by a vascular membrane—the *dental sac.* The papilla becomes transformed into the dentine and pulp of the future tooth, and the enamel is deposited upon its surface by the epithelial-cells of the dental germ. The root of the tooth, with its covering of cement, is formed at a later period, when the tooth is beginning to grow up through the gum, by a gradual elongation of the base of the papilla. The shaping of this into the form of the root is determined by a growth of the epithelium of the edge of the enamel germ, which extends in the form of a fold (the *epithelial sheath* of v. Brunn) towards the future apex of each fang.

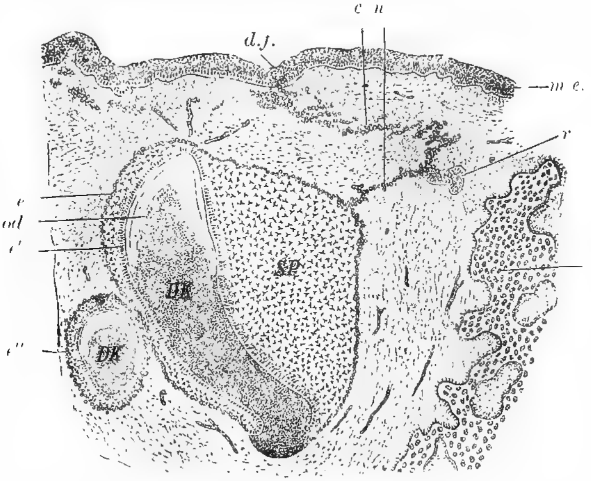


FIG. 432.—SECTION OF A DEVELOPING INCISOR TOOTH OF A HUMAN EMBRYO. (Röse.) THE SECTION ALSO INCLUDES THE GERM OF THE ADJACENT TOOTH.

DK, dental papilla; *od*, odontoblasts; *b*, bone of jaw; *e*, *e'*, outer and inner layers of enamel organ; *SP*, enamel pulp; *d.f.*, dental furrow; *c*, remains of common dental germ or lamina; *n*, neck or bridge of cells connecting this with the enamel organ; *m.e.*, mouth-epithelium; *e''*, enamel organ of adjacent tooth-germ; *r*, reserve germ of permanent tooth.

Formation of the enamel.—Before the enamel appears, the dental germ undergoes a peculiar transformation of its previously polyhedral epithelium-cells into three layers of modified cells, fig. 432. One of these is a layer of columnar cells (*ameloblasts*, fig. 433, *a*), immediately covering the surface of the dentine. The ameloblasts form the enamel prisms: the latter are preceded by a fibrous formation (fig. 434, *f*) followed by a deposition of calcareous salts in the form of small globules. These changes take place altogether external to the formative cells or ameloblasts. The cells next to the dental sac form a single layer of cubical epithelium (fig. 432, *e*). Nearly all the other cells of the dental germ become transformed into branching corpuscles (fig. 432, *SP*; fig. 433, *p*) communicating by their processes, and forming a network. The dental germ, thus modified, is known as the *enamel organ.*

Formation of the dentine.—This is formed by calcification of the surface of the papilla. At this surface there is a well-marked layer of odontoblasts (fig. 435, *od*; fig. 436, *e*). These produce a layer of fibrillated dentinal matrix which forms a sort of cap to the papilla, and soon becomes calcified by the deposition of globules of calcareous matter. Processes of the odontoblasts remain in the dentine as it is forming; in this way the dentinal tubules are produced. Subsequently a second layer of dentine is formed within the first by a repetition of the same process (fig. 436), and others succeed this so that the papilla gradually becomes calcified. A part, however, remains unaltered in the centre of the tooth, and with its covering of odontoblasts forms the pulp.

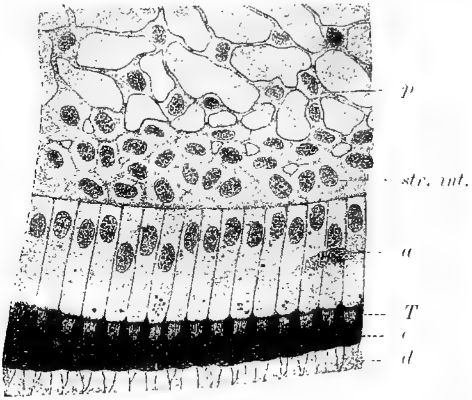


Fig. 433.

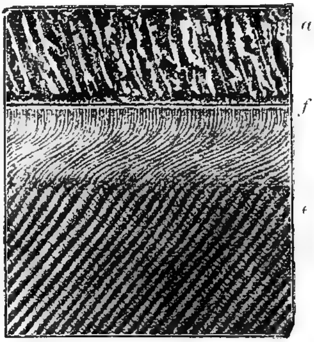


Fig. 434.

Fig. 433.—Section showing the structure of the part of the enamel organ which lies next to the dentine. (Rose.)

d, dentine; *e*, newly formed enamel stained black by osmic acid; *T*, Tomes' processes from the ameloblasts, *a*; *str. int.*, stratum intermedium of enamel organ; *p*, branched cells of enamel pulp.

Fig. 434.—Developing enamel showing ameloblasts and the fibrous substance produced by these cells, which forms the basis of the enamel prisms. (From a photograph by Leon Williams.)

a, portions of the ameloblasts; *f*, fibrous basis of enamel prisms; *e*, calcified part of enamel.

The ten milk-teeth are produced in each jaw in the manner described. These, however, become lost within a few years after birth, and are replaced by permanent teeth in much the same way that a new succession of hair occurs. A small outgrowth takes place at an early period from the dental germ close to each of the milk-teeth (fig. 431, D, *fp*); this eventually becomes the germ of the corresponding permanent tooth. It gradually enlarges, acquires a papilla, forms an enamel organ: in short, passes through the same phases of development as the germ of the milk-tooth; and when the milk-tooth drops out of the jaw in consequence of the absorption of its roots (by osteoclasts) the permanent tooth grows up into its place.

There are six permanent teeth in each jaw which do not succeed milk-teeth; these are the permanent molars. They are developed from an extension backwards on each side of the jaw of the original epithelial thickening or common dental germ and by the down-growth from this into the corium of three successive special germs at comparatively long intervals of time. From these special germs the tissues of the permanent molars become formed in a manner exactly similar to that in which the milk-teeth are developed.

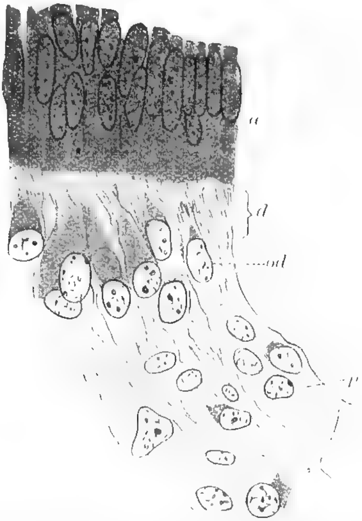


Fig. 435. -Part of a section of developing tooth of pig. (v. Korff.)

a, ameloblasts; *d*, fibres of the first formed layer of dentine; *od*, odontoblasts; *p*, pulp. The fibres of the pulp are seen to be in continuity with those which enter into the formation of the dentine.

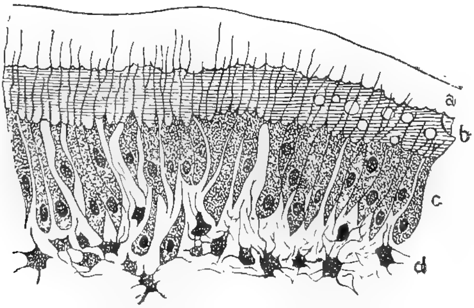


Fig. 436.—Part of section of developing tooth of young rat, showing the mode of deposition of the dentine. Highly magnified.

a, outer layer of fully calcified dentine; *b*, uncalcified matrix, with a few nodules of calcareous matter; *c*, odontoblasts with processes extending into the dentine; *d*, pulp. The section being stained, the uncalcified matrix is coloured, but not the calcified part.

LESSON XXIX.

THE TONGUE AND THE GUSTATORY ORGANS. THE MUCOUS MEMBRANE OF THE MOUTH. THE PHARYNX AND ŒSOPHAGUS.

1. Sections of the tongue vertical to the surface, stained with hæmatoxylin and eosin. The sections should be taken from different parts and include all three kinds of papillæ.

2. Sections of injected tongue.

3. Sections of the papilla foliata of the rabbit, stained with hæmatoxylin and eosin: these show taste-buds *in situ*.
The cells composing the taste-buds are studied by teasing osmic preparations of the papilla foliata; the nerve endings are seen in sections of papillæ foliatæ which have been treated by Golgi's osmic-bichromate-silver method.

4. Sections of the pharynx and of the œsophagus stained with hæmatoxylin and eosin.

THE TONGUE.

The **tongue** is mainly composed of striated muscular fibres, running some longitudinally, others transversely. It is covered by a mucous membrane, the epithelium of which, like that of the rest of the mouth, is thick and stratified, and conceals microscopic papillæ (fig. 437) like those of the skin. Besides these, the upper surface of the organ is covered with large papillæ, which give it a rough appearance. These, which are termed the *lingual papillæ*, are of three kinds: (1) About twelve or thirteen comparatively large circular projections, each of which is surrounded by a narrow groove (fossa), external to which the mucous membrane is raised above the general level (vallum). These papillæ lie in a V-shaped line with the apex of the V towards the back of the tongue; they receive filaments of the glosso-pharyngeal nerve, and have taste-buds in the epithelium which covers their sides, and (in man but not in most animals) in that of the side of the vallum. They are known as the *circumvallate papillæ* (figs. 438, 441). (2) All the rest of the papillary surface of the tongue is covered by *conical papillæ*, so named from the conical pointed cap of epithelium which is borne by each; sometimes this cap is fringed with fine epithelial filaments, when they are termed *filiform* (fig. 439). In the cat tribe the conical papillæ are claw-shaped or recurved: they are hard and horny, and in the process of licking they produce the effect of scraping. (3) Scattered here and there amongst the conical papillæ are larger papillæ, the *fungiform* (fig. 440). These are very vascular, and have a redder appearance than the rest: they lie partly

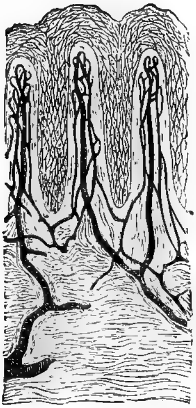


Fig. 437.—Section of mucous membrane of mouth, showing three microscopic papillæ and stratified epithelium. The blood-vessels have been injected. (Toldt.)

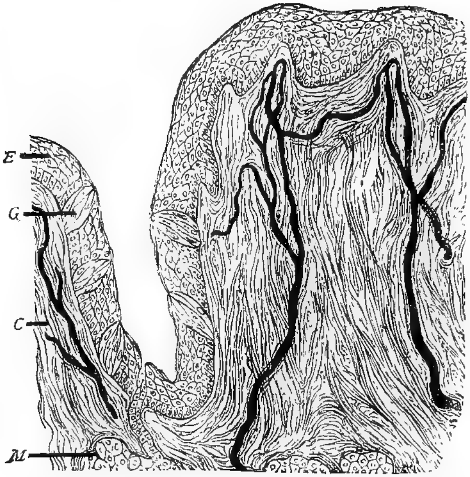


Fig. 438.—Section of circumvallate papilla, human. The figure includes one side of the papilla and the adjoining part of the vallum. Magnified 150 diameters. (Heitzmann.)

E, epithelium; *G*, taste-bud; *C*, corium with injected blood-vessels; *M*, gland with duct.

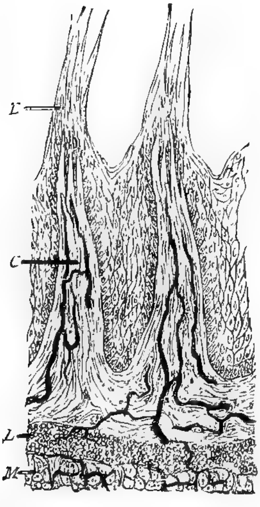


Fig. 439.—Section of two filiform papillæ, human. (Heitzmann.)

E, epithelium; *C*, corium; *L*, lymphoid tissue; *M*, muscular fibres of tongue.

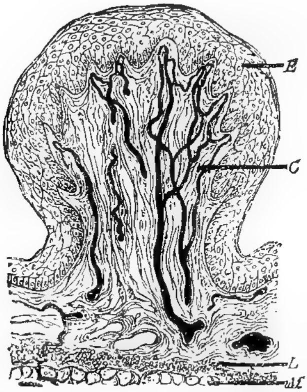


Fig. 440. Section of fungiform papilla, human. (Heitzmann.) Letters as in previous figure.

embedded in little depressions of the mucous membrane. They have a certain number of taste-buds in their epithelium and receive branches from one or other of the taste-nerves.

Small tubular glands may be seen between the superficial muscular fibres sending their ducts to the surface. Most of these glands secrete mucus, but those which open into the trenches of the circumvallate papillæ, and a few others elsewhere, yield an albuminous secretion (*serous glands of tongue, glands of Ebner*).

The mucous membrane at the back of the tongue contains a large amount of lymphoid tissue, continuous with that of the tonsils (p. 241) and having a similar arrangement and structure.

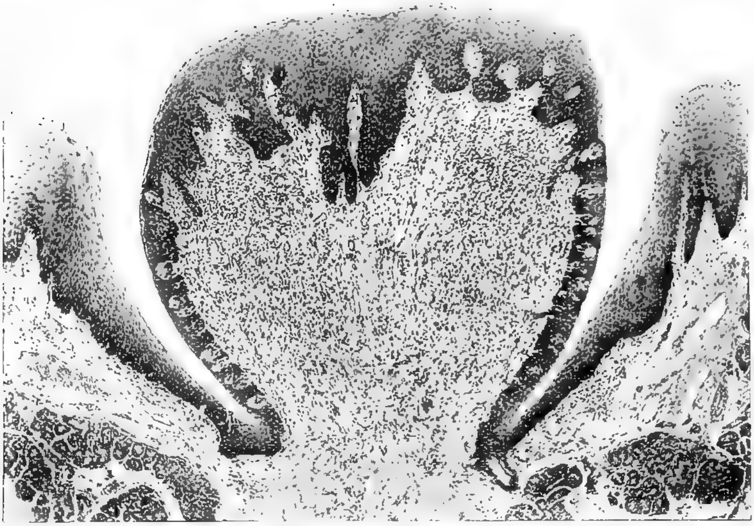


FIG. 441.—SECTION OF CIRCUMVALLATE PAPILLA OF MONKEY. Magnified 50 diameters.

Notice the irregularly papillated, flat surface of the papilla: the deep trench surrounding it: the taste-buds in the epithelium at the sides of the papilla, but none on the opposite side of the trench: the serous glands below it (the duct of one of these is seen opening into the bottom of the trench).

TASTE-BUDS.

The minute gustatory organs which are known as *taste-buds* or taste-bulbs may be seen in sections which pass through the papillæ vallatæ or the papillæ fungiformes; they are also present here and there in the epithelium of the general mucous membrane of the tongue, especially at the back and sides, and some are found upon the under surface of the soft palate, and on the posterior surface of the epiglottis. But they are most easily studied in the papillæ foliatæ of the rabbit (fig. 442), two small oval areas lying on each side of the back of the tongue, and marked transversely with a number of ridges or laminæ with intervening trenches. Sections across the ridges show numerous taste-buds embedded in the thick epithelium which clothes their sides (fig. 443).

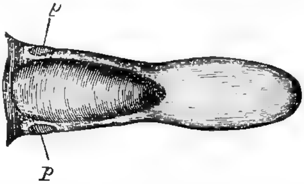


FIG. 442.—TONGUE OF RABBIT, SHOWING THE SITUATION OF THE PAPILLÆ FOLIATÆ, *p*.

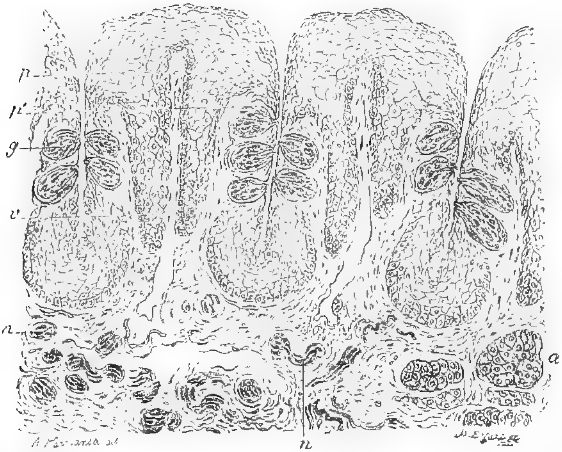


FIG. 443.—VERTICAL SECTION OF PAPILLA FOLIATA OF THE RABBIT, PASSING ACROSS THE FOLIÆ. (Ranvier.)

p, central lamina of the corium; *v*, section of a vein, which traverses the folium: *p′* lateral lamina in which the nerve-fibres run; *g*, taste-bud; *n*, sections of nerve-bundles; *a*, serous gland.

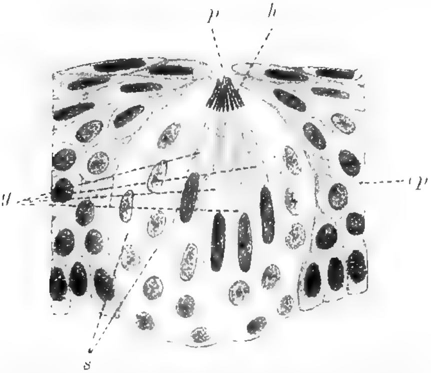


FIG. 444.—A TASTE-BUD WITHIN THE STRATIFIED EPITHELIUM OF THE TONGUE. (Sobotta.) Magnified 500 diameters.

g, gustatory cells; *s*, sustentacular cells; *ep*, epithelium; *p*, gustatory pore; *h*, hairlets.

The taste-buds are ovoid clusters of epithelium-cells which lie in cavities in the stratified epithelium (fig. 444). The base of the taste-buds rests upon the corium of the mucous membrane, and receives a branch of the glosso-pharyngeal nerve; the apex is narrow and communicates with the cavity of the mouth by a small pore in the superficial epithelium (*gustatory pore*, fig. 444, *p*).

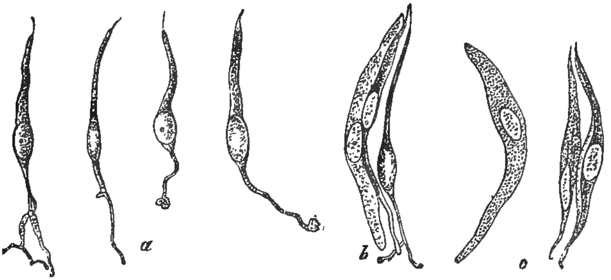


FIG. 445.—VARIOUS CELLS FROM TASTE-BUD OF RABBIT. (Engelmann.) 600 diameters.

a, four gustatory cells from central part; *b*, two sustentacular cells, and one gustatory cell, in connexion; *c*, three sustentacular cells.

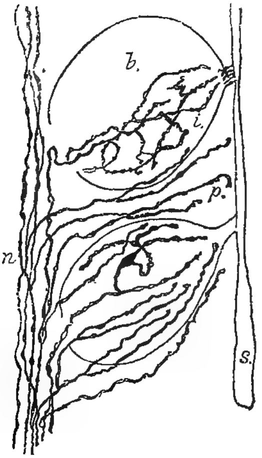


FIG. 446.—NERVE-ENDINGS IN TASTE-BUDS. (G. Retzius.)

n, nerve-fibres; *b*, taste-buds in outline; *i*, ending of fibrils within taste-bud; *p*, ending in epithelium between taste-buds; *s*, sulcus of papilla foliata into which the gustatory pores open.

The cells which compose the taste-bud are of two kinds, viz.: 1. The *gustatory cells* (fig. 445, *a*). These are delicate fusiform or bipolar cells composed of cell-body or nucleated enlargement and of two processes, one distal, the other proximal. Of these the distal is nearly straight, and passes towards the apex of the taste-bud, where it terminates in a small, highly refracting cilium-like appendage (*taste-hairlet*), which projects into the gustatory pore above mentioned; the cell-body does not itself quite reach the pore. The proximal process is more delicate than the other, and is often branched and varicose. The nerve-fibres to the taste-bud (fig. 446) terminate in ramifications amongst these cells (G. Retzius). 2. The *sustentacular cells* (fig. 445, *c*). These are elongated cells, mostly flattened, and pointed at their ends; they lie between the gustatory cells, which they thus appear to support, and in addition they form a sort of envelope or covering to the taste-bud. Between the cells of the taste-bud lymph-corpuscles are often seen, having probably wandered hither from the subjacent mucous membrane. Connective-tissue fibrils penetrate between the taste-bud and the stratified epithelium in which it is embedded (Drasch).

According to M. Heidenhain no sharp distinction can be drawn between gustatory and sustentacular cells, since all grades of transition are found.

MOUTH, PHARYNX AND ŒSOPHAGUS.

The **mucous membrane of the mouth** is lined by a stratified epithelium (fig. 447) into which vascular, and, in some parts, nerve-containing papillæ of the corium project. The corium is formed of connective tissue and contains within and beneath it a large number of small secretory glands (buccal glands). Most of these secrete mucus, but some are of the mixed type (see under Salivary Glands, in next Lesson): this is the case, for example, with the glands of the lips. The ducts of the buccal glands open everywhere upon the surface of the membrane; the large ducts belonging to the salivary glands are also open into the mouth.

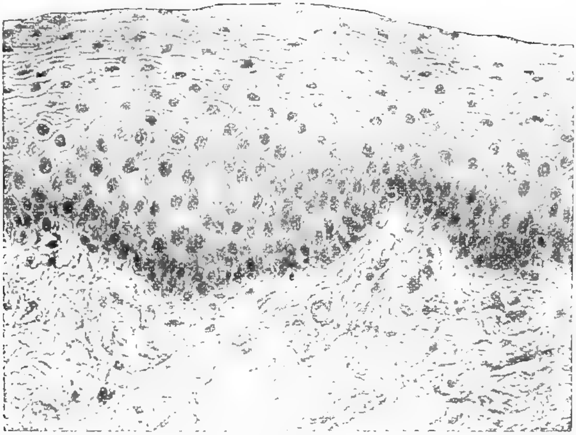


FIG. 447.—SECTION OF THE STRATIFIED EPITHELIUM OF THE FAUCES OF THE RABBIT. Magnified 240 diameters.

The **pharynx** is composed of a *fibrous membrane* which is encircled by striated muscles (the *constrictors*), and lined by *mucous membrane* with which the fibrous membrane is connected by areolar tissue. The mucous membrane is covered on its inner surface over the upper part of the pharynx with ciliated epithelium; this is continuous above with that of the nostrils, and through the Eustachian tube with that of the tympanum. Below the level of the soft palate the epithelium is stratified like that of the mouth and gullet, into which it passes. In certain parts the mucous membrane contains a large amount of lymphoid tissue, and everywhere numerous mucous glands open on its surface.

The **œsophagus** or gullet, which passes from the pharynx to the stomach, consists of an outer *fibrous* or *areolar covering*, a *muscular coat*, a lining *mucous membrane*, and intervening connective tissue forming the *submucous* or *areolar coat* (fig. 448). The muscular coat is composed of striated muscle in about its upper third only, the rest being of the plain variety. There are two layers of the muscular coat—an outer layer, in which the bundles of fibres run longitudinally, and an inner, in which they have a circular arrangement. The mucous membrane is lined by a stratified epithelium, into which papillæ from the corium project. The corium is formed of areolar tissue; its limits are marked externally by a narrow layer of longitudinally disposed plain muscular fibres, the *muscularis mucosæ*. This is separated from the proper muscular coat by the areolar coat, which contains the larger branches of the blood-vessels and lymphatics, and also the mucous glands of the membrane. The ducts of these glands are large and usually pass through a nodule of lymphoid tissue, lymph-cells from which infiltrate the epithelium of the duct and may pass out into its lumen.

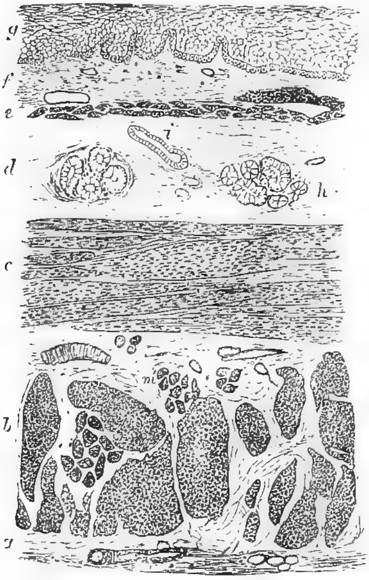


FIG. 448. SECTION OF THE HUMAN ŒSOPHAGUS. (v. Horsley.)

The section is transverse, and from near the middle of the gullet. *a*, fibrous covering; *b*, divided fibres of the longitudinal muscular coat; *c*, transverse muscular fibres; *d*, submucous or areolar layer; *e*, muscularis mucosæ; *f*, mucous membrane with papillæ; *g* laminated epithelial lining; *h*, mucous gland; *i*, gland duct; *m'*, striated muscular fibres in section.

Besides these mucous glands, there are met with both at the upper or laryngeal part of the œsophagus and at the lower or cardiac end a certain number of small tubulo-racemose glands of a different character. They are confined to the mucous membrane, not penetrating the muscularis mucosæ, and their ducts open upon and not between the papilla of the mucous membrane. They closely resemble the tubulo racemose cardiac glands of the stomach (see fig. 466, p. 333), and it is usually found that the epithelium of the surface in the immediate neighbourhood of their ducts is similar to that lining the stomach.

There are two ganglionated nerve-plexuses in the œsophagus, one in the muscular coat and one in the submucous coat; they resemble in position and structure those of the intestine.

LESSON XXX.

THE SALIVARY GLANDS.

1. SECTION of submaxillary gland (dog). The gland may be hardened in alcohol or formol and stained with hæmatoxylin-eosin or with iron-hæmatoxylin by Heidenhain's method. Notice the acini filled with clear (mucus-secreting) cells, the nuclei of which usually lie near the basement-membrane. Notice here and there, outside the clear cells, demilunes or crescents of small darkly stained granular-looking (serous) cells. Observe also the sections of the ducts with their striated columnar epithelium. If possible find a place where one of the ducts is passing into the alveoli. Sketch under a high power.

2. Study sections of parotid and sublingual glands prepared in a similar way, and notice the differences between the three glands.

3. Examine small pieces of both submaxillary and parotid gland of the dog or cat fresh in 2 per cent. salt solution. In the submaxillary gland notice that the alveolar cells are swollen out with large granules or droplets of mucigen, which swell up in water to form large clear vacuoles. Dilute acids and alkalies produce a similar change, but more rapidly. The cells of the parotid gland are also filled with granules, but they are smaller. Their granules are swollen up and dissolved by dilute acids and alkalies. Make a sketch from each preparation under a high power.

The granules are not seen in preparations that have been in alcohol, but osmic acid preserves them moderately well; they are well seen in sections from picric acid hardened glands.

4. To study the changes which the alveolar cells undergo during secretion, pilocarpine is administered to an animal in sufficient amount to produce copious salivation; after half an hour the animal is killed and its salivary glands are examined as in § 3.

The **salivary glands** may be looked upon as typical of secreting glands in general. They are composed of a number of *lobules* bound together loosely by connective tissue. Each small lobule is formed of a group of irregularly saccular or tubular *alveoli* or *acini* from which a small duct passes, and this unites with others to form larger ducts. A main duct eventually leaves the gland to open upon the inside of the mouth.

The alveoli are enclosed by a basement-membrane, which has flattened branched cells on its inner surface, next to the epithelium (fig. 449). The membrane may be shown by teasing the fresh gland substance in water (Langley). This basement-membrane is continued along the ducts. Within it is the epithelium, which in the alveoli is composed of polyhedral cells (fig. 450, *a*), but in the ducts is regularly columnar, except in that part of the duct which immediately opens into the alveoli (*junctional part*); in this it is flattened (*d'*). The columnar epithelium of the ducts is peculiar, in that the cells show a distinction into two unequal zones, an outer, larger, striated zone, and an inner, smaller, granular one (fig. 450, *d*).

The cells of the alveoli differ according to the substance they secrete. In alveoli which secrete mucus, such as those of most of the smaller glands which open on the mucous membrane of the mouth, and contribute to the production of saliva (fig. 451), and some of the alveoli of the submaxillary and sublingual glands, the cells, if examined in normal saline solution or after hardening with alcohol, are clear and swollen. But if examined rapidly in serum, or in solutions of salt of from 2 to 5 per cent., they are often seen to be occupied by large and distinct granules (fig. 452, *a*) (Langley) which become swollen up under the influence of dilute acid (*b*) These granules can also be rendered visible by certain methods of staining. Granules are not

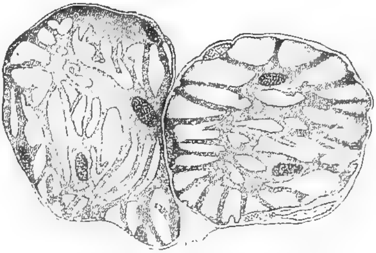


FIG. 449.—MEMBRANA PROPRIA OF TWO ALVEOLI. (v. Ebner.)
Magnified 600 diameters.

The preparation was from a mucous gland of the rabbit.

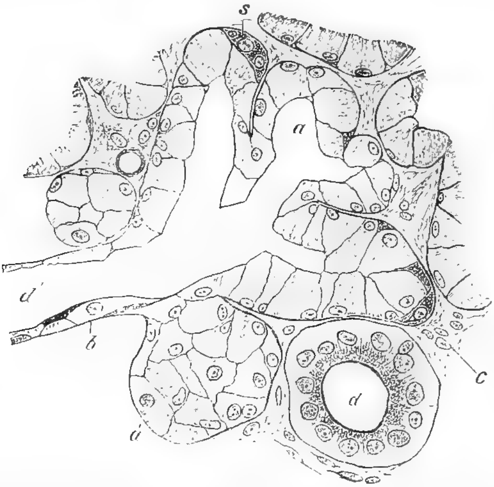


FIG. 450.—SECTION OF THE SUBMAXILLARY GLAND OF THE DOG, SHOWING THE COMMENCEMENT OF A DUCT IN THE ALVEOLI. Magnified 425 diameters.

a, one of the alveoli, several of which are in the section shown grouped around the commencement of the duct, *d'*; *a'*, an alveolus, not opened by the section; *b*, basement-membrane in section; *c*, interstitial connective tissue of the gland; *d*, section of a duct which has passed away from the alveoli, and is now lined with characteristically striated columnar cells; *s*, crescentic group of darkly stained cells at the periphery of an alveolus.

present as such in all mucus-secreting cells, but in many have become blended together and transformed into a substance which is known as *mucigen* which distends the cell. The mucigen is dissolved out and discharged as *mucus* into the lumen of the alveolus and into the ducts, when the gland is stimulated to activity. After such discharge, the cells, instead of having a clear appearance, look finely granular, and are much smaller; they also stain more deeply with hæmatoxylin (compare figs. 453 and 454). These cells are

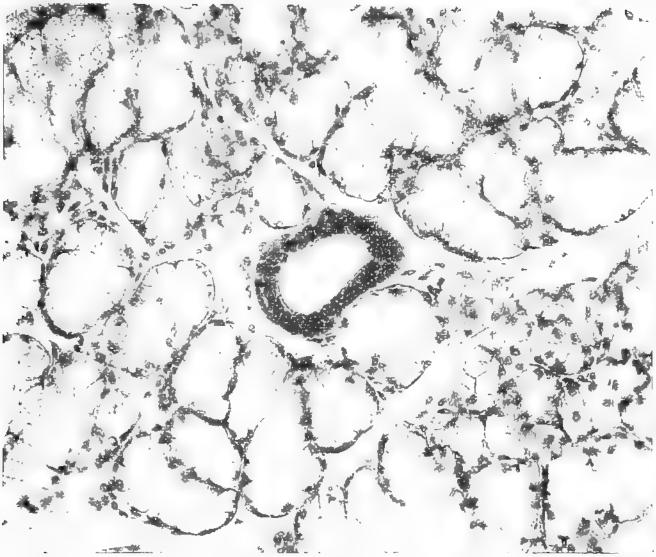


FIG. 451.—SECTION OF A MUCOUS SALIVARY GLAND (ONE OF THE SMALL GLANDS OF THE BUCCAL MUCOUS MEMBRANE). Magnified 200 diameters.

In the middle of the figure is seen the section of a duct.

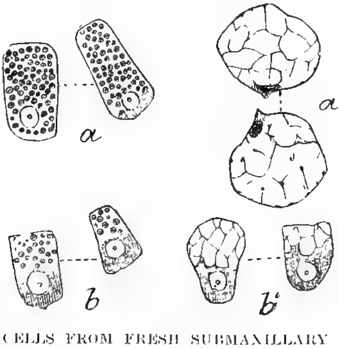


FIG. 452.—MUCOUS CELLS FROM FRESH SUBMAXILLARY GLANDS OF THE DOG. (Langley.)

a, from a resting or loaded gland; *b*, from a gland which has been secreting for some time; *a*,' *b*', similar cells which have been treated with dilute acid.

known as *mucous cells*. But in most mucous alveoli certain of the cells do not contain mucigen, but small albuminous granules; these cells often form groups which lie next to the basement-membrane (figs. 453, *c*, and 455). These groups are the so-called *crescents of Gianuzzi*; their constituent cells are known as *marginal* or *serous cells*. Special diverticula pass from the lumen of the alveoli between the mucous cells to penetrate to the crescents and to branch amongst and within their constituent cells; these diverticula are best shown by the Golgi method of staining (fig. 456; also fig. 463).

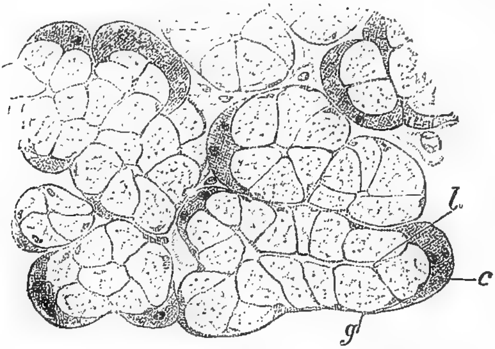


FIG. 453.—SECTION OF A DOG'S SUBMAXILLARY, AFTER A PROLONGED PERIOD OF REST. (Ranvier.)
l, lumen of alveolus; *g*, mucus-secreting cells; *c*, crescent, formed of albuminous cells.

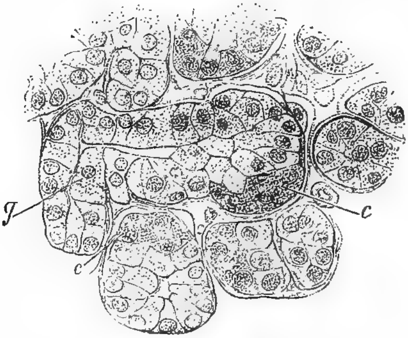


FIG. 454.—SUBMAXILLARY OF DOG, AFTER A PERIOD OF ACTIVITY. (Ranvier.)
The mucus-secreting cells, *g*, have discharged their secretion, and are smaller and stain better; the albuminous cells of the crescents, *c*, are enlarged.

The serous cells are characteristic of purely *serous alveoli* (fig. 455), in which none of the cells secrete mucus, but watery or albuminous saliva. In these when the gland has been long at rest the cells are filled with granules, which do not swell with water nor form mucin; they appear to be of protein nature, and probably yield to the secretion of the gland its ferment (ptyalin) and its albumin. The granular substance within the cell is not the ferment, but the ferment is formed from it when the secretion is poured out. Hence it has been termed *zymogen* (mother of ferment). As Langley showed, the outer part of each cell becomes clear and free from granules after secretion (fig. 457). Sometimes the change is found to occur in some cells and not in others (fig. 458).

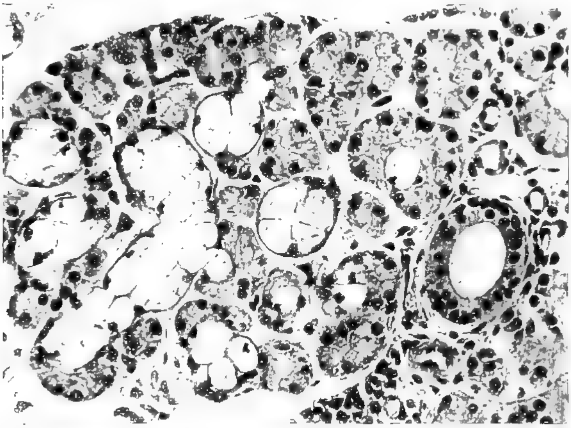


FIG. 455.—SECTION OF HUMAN SUBLINGUAL. Magnified 200 diameters. (Photographed from a preparation by Prof. M. Heidenhain.)

Most of the alveoli shown in the figure are serous, but some are mixed, containing chiefly mucous cells but also crescentic groups of serous cells.

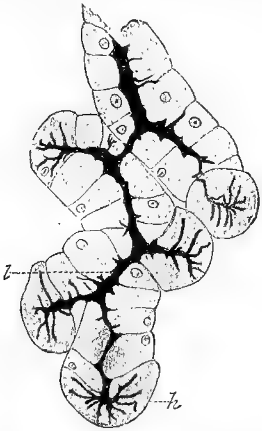


FIG. 456. ALVEOLI OF HUMAN SUBLINGUAL GLAND PREPARED BY GOLGI METHOD. (E. Müller.)

l, lumen stained, with lateral diverticula passing between and into mucus-secreting cells; *h*, longer diverticula penetrating into the "crescent" cells.

The cells lining the ducts of the ordinary glands are also occupied by granules which have been found to alter in number and size with varying states of secretion (fig. 459).

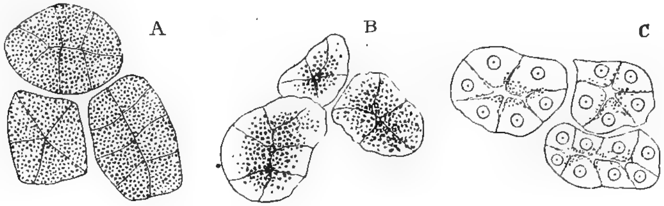


Fig. 457.—Alveoli of a serous gland. *A*, at rest. *B*, after a short period of activity. *C*, after a prolonged period of activity. (Langley.)
In *A* and *B* the nuclei are obscured by the granules of zymogen.

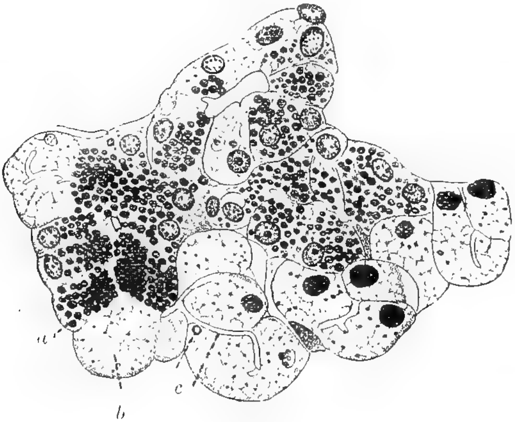


Fig. 458.—Submaxillary gland of rabbit. (E. Müller.)
The cells, which are all serous, are in different functional states, as indicated by the condition and staining of the granules. *a*, cell filled with darkly stained granules; *b*, clear cell; *c*, secretory canaliculi penetrating into the cells.

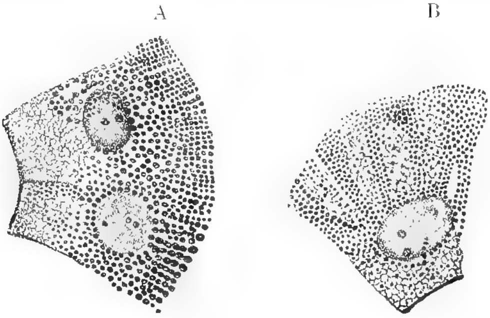


Fig. 459.—Cells from duct of parotid.
A, prior to secretion; *B*, after secretion (Mislawski and Smirnow).

In nearly all animals the parotid glands are composed of purely serous alveoli; in man and most animals the submaxillary and sublingual glands have not only both serous and mucous alveoli (figs. 455, 460), but also "mixed" alveoli, *i.e.*, alveoli containing both serous and mucous cells. The detached anterior part of the sublingual gland, which in man is comparatively small, has purely mucous alveoli.

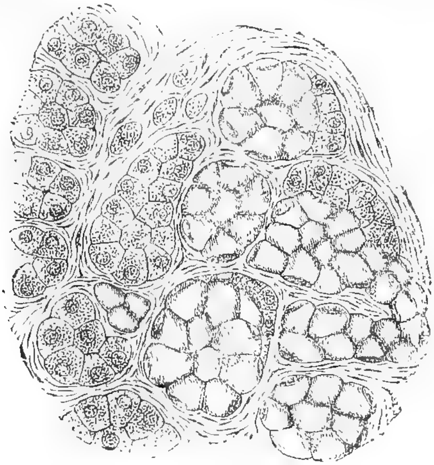


FIG. 460.—SECTION OF PART OF THE HUMAN SUBMAXILLARY GLAND. (R. Heidenhain.)

To the right of the figure is a group of mucous and mixed alveoli; to the left a group of serous alveoli.

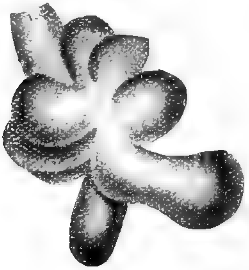


FIG. 461.—ALVEOLI FROM MUCOUS PORTION OF THE HUMAN SUBMAXILLARY GLAND, PARTLY UNRAVELLED. (Peiser.)

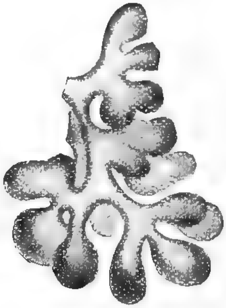


FIG. 462.—ALVEOLI FROM SEROUS PORTION OF THE HUMAN SUBMAXILLARY GLAND, PARTLY UNRAVELLED. (Peiser.)

When the glands are unravelled and examined with the microscope it is found that the mucous and serous alveoli are somewhat different in shape, the mucous alveoli being larger, more uniform in shape, and linked on to the ducts by shorter and wider intermediate or junctional portions (compare fig. 461, which is from a mucous part of the human submaxillary, with fig. 462 from a serous part).

The largest ducts have a wall of connective tissue outside the basement-membrane, and also a few plain muscle-cells. The blood-vessels of the gland form a capillary network around each alveolus. The lymphatics commence in the form of lacunar vessels in the areolar tissue between the alveoli. Lymph-nodules are occasionally found in the interstitial connective tissue. The nerve-fibres of the gland, which are derived in the case of the larger salivary glands both from the cerebro-spinal nerves and from the sympathetic, pass through ganglia before proceeding to their distribution. They ramify as fine varicose fibrils amongst the alveolar cells (fig. 463); many are distributed to the blood-vessels.

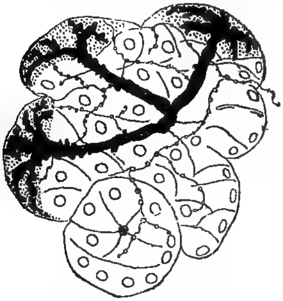


FIG. 463.—ALVEOLI OF THE SUB-MAXILLARY GLAND OF THE DOG. (G. Retzius.) Golgi method.

The extensions of the lumen into the crescents of Gianuzzi are shown, and also the endings of nerve-fibrils amongst the cells of the alveoli.

Development.—The salivary glands are developed as buds from the epithelium of the buccal cavity, at first solid but becoming gradually hollowed out. To begin with they are simple, but undergo ramification as they extend into the mucous membrane and submucous tissue.

LESSON XXXI.

THE STOMACH.

1. Vertical longitudinal sections through the cardia, including the lower end of the œsophagus and the adjacent cardiac portion of the stomach. These are intended to show the abrupt transition of the stratified epithelium of the œsophagus into the columnar epithelium of the stomach, and also the character of the gastric and œsophageal glands in the immediate neighbourhood of the cardia. The sections may be stained with hæmatoxylin and eosin.

2. Sections of the fundus of the stomach cut perpendicularly to the surface of the mucous membrane.

In these sections the general arrangement of the coats of the stomach is to be studied. Sketches are to be made under a low power illustrating this arrangement, and others under a high power showing the structure of the glands of the mucous membrane.

Measure the whole thickness of the mucous membrane, the thickness of the muscular coat, the size of the columnar epithelium-cells of the surface, and that of the cells in the deeper parts of the glands.

3. Sections of the mucous membrane of the fundus, cut parallel to the surface.

These sections will show better than the others the arrangement of the cells in the glands.

4. Vertical sections of the mucous membrane from the pyloric region of the stomach. If the section is taken longitudinally through the pylorus, the transition of the gastric glands into the glands of Brünner of the duodenum will be made manifest. Make a sketch under a low power of one of the glands in its whole length, filling up some of the details with the high power.

5. Study the arrangement of the blood-vessels in vertical sections of the wall of a stomach the vessels of which have been injected.

The wall of the **stomach** consists of four coats, which, enumerated from without in, are as follows, viz.: *serous*, *muscular*, *areolar* or *sub-mucous*, and *mucous membrane* (fig. 464).

The *serous coat* is a layer which is derived from the peritoneum. It is deficient along the lines of the lesser and greater curvatures.

The *muscular coat* consists of three layers of plain muscular fibres. Of these the bundles of the outer layer run longitudinally, those of the middle layer circularly, and those of the inner layer obliquely. The longitudinal and circular bundles become thicker and stronger towards the pylorus; at the pylorus itself the circular layer is greatly thickened to form a sphincter muscle. The oblique fibres are only present over the fundus.

The *areolar* or *submucous coat* is a layer of areolar tissue, which serves to unite the mucous membrane loosely to the muscular coat; in it ramify the larger branches of the blood-vessels and lymphatics.

The *mucous membrane* is a soft thick layer, generally somewhat corrugated in the empty condition of the organ. Its inner surface is covered by columnar goblet-cells, all of which secrete mucus. They are prolonged into the ducts of the glands, but when these divide to form the tubules the cells become shorter, and lose their mucus-secreting character. Where the œsophagus passes into the stomach the stratified epithelium which lines the gullet gives place abruptly to the columnar epithelium of the stomach (fig. 465).

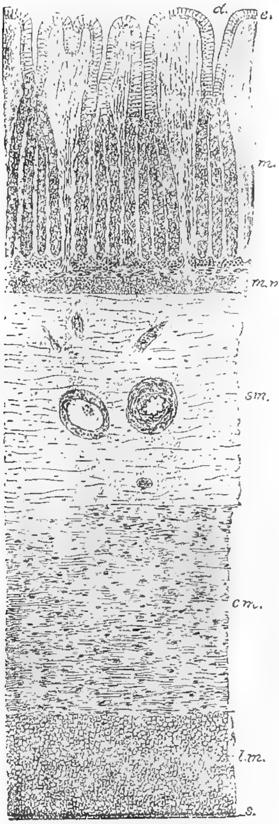


FIG. 464. DIAGRAM OF SECTION THROUGH THE COATS OF THE STOMACH. (Mall.)

m, mucous membrane; *e*, epithelium; *d*, orifice of gland duct; *m.m.*, muscularis mucosæ; *sm.*, submucosa; *c.m.*, circular muscular layer; *l.m.*, longitudinal muscular layer; *s*, serous coat.

In some animals the stratified epithelium of the œsophagus is continued over a more or less extensive tract of the gastric mucous membrane, but it always ends by a similar sharply defined line.

The thickness of the gastric mucous membrane is due to the fact that it is largely made up of long tubular glands, which open upon the inner surface. Between the glands the mucous membrane is formed of reticular tissue with some lymph-cells in the meshes. Externally the mucous membrane is bounded by the *muscularis mucosæ*, which consists of an outer longitudinal and an inner circular layer of plain muscular fibres.

Gastric glands.—These are formed of a basement-membrane lined with epithelium. Each gland consists of *secreting tubules*, from one to four in number, opening at the surface into a larger tube, the *duct* of the gland. The duct is in all cases lined by mucus-secreting epithelium of the same character as that which covers the inner surface of the mucous membrane, but the epithelium of the secreting tubules is different from this, and also differs somewhat in the glands of different regions of the organ. The following varieties of gastric glands are met with:—

(1) *Glands of the cardia.*—These are comparatively few in number. They are usually found only close to the œsophageal opening (cardia) and are of two kinds: (*a*) simple tubules, very similar to the crypts of Lieberkühn of the intestine, and (*b*) small tubulo-racemose glands (fig. 466). The latter are commonest in man; the former occur in considerable number in some animals. The secreting tubules of the racemose glands are lined by cells

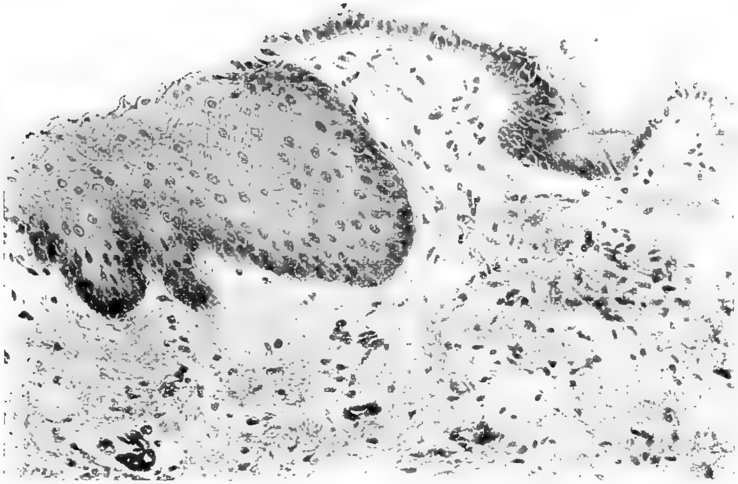


FIG. 465.—SECTION OF THE WALL OF THE STOMACH OF THE DOG AT THE PLACE WHERE THE STRATIFIED EPITHELIUM OF THE ŒSOPHAGUS IS CONTINUED INTO THE COLUMNAR EPITHELIUM OF THE GASTRIC MUCOUS MEMBRANE. Magnified 200 diameters.

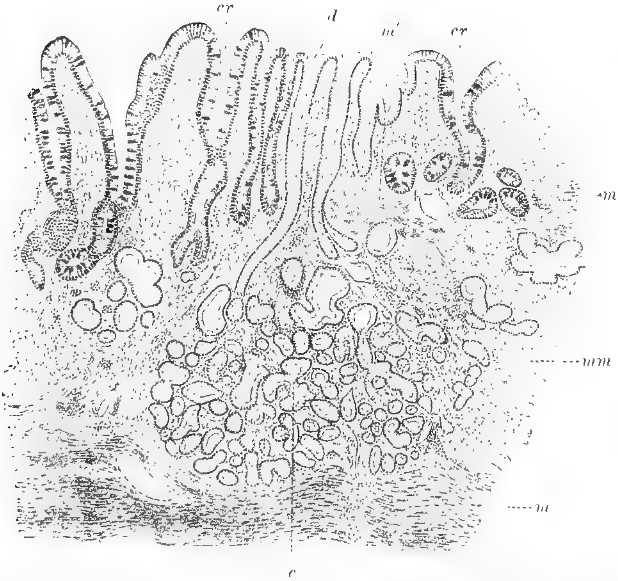


FIG. 466.—SECTION OF HUMAN STOMACH NEAR THE CARDIAC. (v. Ebner, after J. Schaffer.) Magnified 45 diameters.

c, cardiac glands; *d*, their ducts; *cr*, glands similar to crypts of Lieberkuhn, with goblet-cells; *mm*, mucous membrane; *m*, muscularis mucosæ; *m'*, muscular tissue within mucous membrane.

which are granular in appearance and of a short columnar form, and of the same nature throughout the length of the tubule, except near the orifice

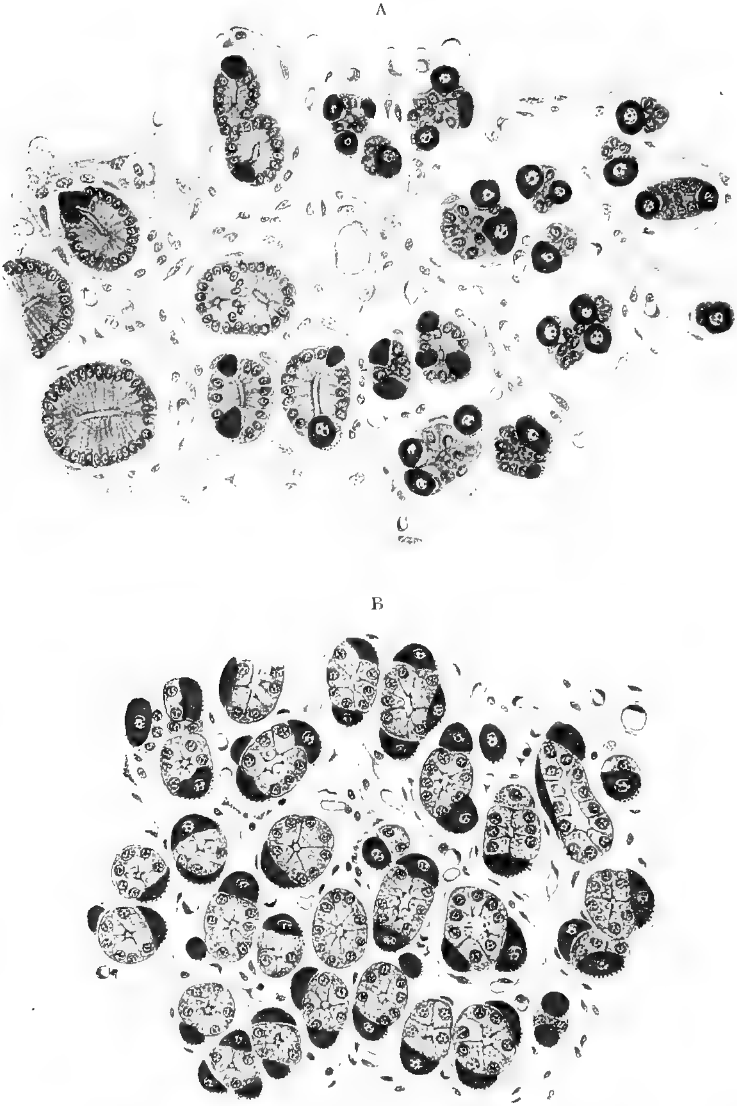


FIG. 467.—SECTIONS OF THE MUCOUS MEMBRANE OF THE FUNDUS OF THE DOG'S STOMACH PASSING ACROSS THE LONG AXIS OF THE GLANDS.

A, Section close to but not quite parallel with the surface, including on the left the gland ducts and on the right the commencing gland tubules. Notice the oval oxyntic or acid-forming cells of the glands. They begin to appear even between the columnar cells of the ducts.

B, Deeper part of the same section, showing the lumina of the gland tubules surrounded by principal or pepsin-yielding cells, with the oxyntic cells altogether outside them.

(duct), where they give place to columnar mucus-secreting cells. Bensley describes some of the tubules as lined with mucus-secreting cells throughout. Occasionally one or two oxyntic cells are present in the tubules.

Glands of a somewhat similar character occur near the lower end of the œsophagus. At the places where their ducts open the œsophageal epithelium is usually columnar instead of stratified (p. 322).

(2) *Glands of the fundus* (*oxyntic* or *acid-producing glands*) (figs. 464, 467, 468).—In these glands the tubules are usually relatively long and the duct short. The epithelium of the tubules is composed of two kinds of cells. Those of the one kind, which form a continuous lining to the tubule, are somewhat polyhedral in shape, and in stained sections look clearer and smaller than the others, but in the fresh glands, and with certain methods of staining, it can be seen that they are partly filled with granules (fig. 468), which are most numerous in the inner portion of the cell, an outer zone being left clear. After prolonged activity this outer zone increases while the

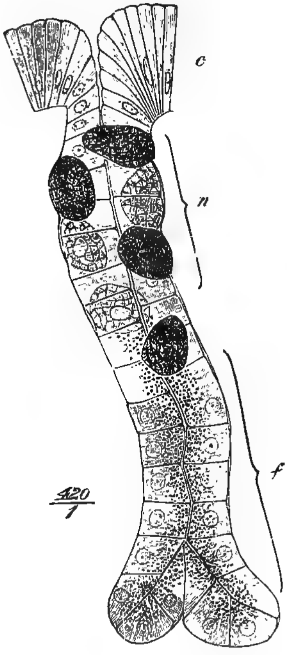


FIG. 468.

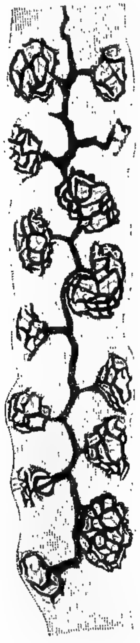


FIG. 469.

FIG. 468.—A FUNDUS GLAND OF SIMPLE FORM FROM THE BAT'S STOMACH. Osmic acid preparation. (Langley.)

c, columnar epithelium of the surface; *n*, neck of the gland with central and parietal cells; *f*, base, occupied only by principal or central cells, which exhibit the granules accumulated towards the lumen of the gland.

FIG. 469.—A FUNDUS GLAND PREPARED BY GOLGI'S METHOD, SHOWING THE MODE OF COMMUNICATION OF THE PARIETAL CELLS WITH THE GLAND-LUMEN. (E. Müller.)

granules diminish in number, as in the analogous cases of the pancreas and parotid glands (Langley). These cells form the pepsin of the gastric juice, the granules within them containing pepsinogen, which is converted into pepsin when discharged. They are known as the *principal* or *chief cells* of the cardiac glands, or, from their relative position in the tubule immediately surrounding the lumen, the *central cells.* Scattered along the tubule, and lying between the principal cells and the basement-membrane, are a number

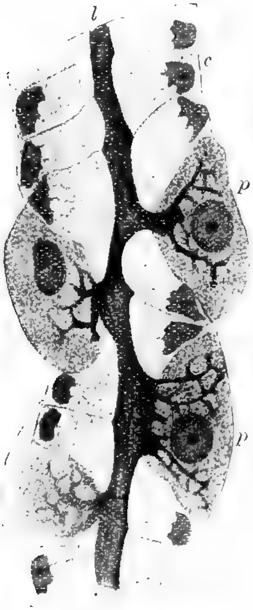


FIG. 470.

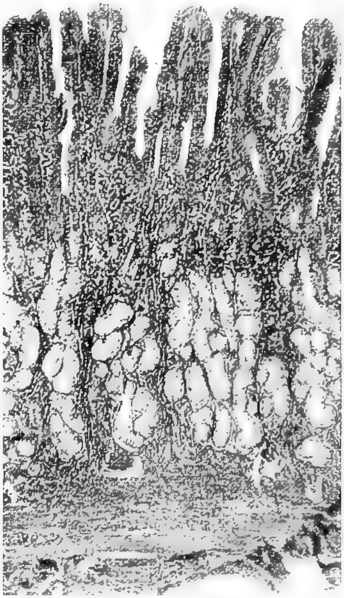


FIG. 471.

FIG. 470.—PART OF TUBULE OF A FUNDUS GLAND, WITH THE LUMEN AND SECRETORY CANALICULI STAINED BLACK; THE GLAND-CELLS ARE ALSO SHOWN. (Zimmermann.)

c, chief or central cells; *p*, parietal or oxyntic cells; *l*, lumen of tubule prolonged into arborescent canaliculi which penetrate to the parietal cells.

FIG. 471.—PYLORIC GLANDS, FROM A SECTION OF THE HUMAN STOMACH. (Photographed from a preparation by Prof. Martin Heidenhain.) Magnified 60 diameters.

of large spheroidal or ovoidal cells. These are the *parietal* or *oxyntic cells,* having been so named by Langley because they are believed to produce the acid of the gastric secretion. Each of these cells is surrounded and penetrated by a network of minute passages, communicating with the lumen of the gland by a fine canal, which passes between the central cells (figs. 469, 470). But in the neck of the gland the parietal cells abut against the lumen, being here wedged in between the mucus-secreting cells (fig. 467, A).

(3) *Glands of the pyloric canal* (fig. 471).—In the glands of the pyloric

canal the ducts are much longer than those of the fundus glands, and the secreting tubules possess cells of only one kind.[1] These correspond to the principal cells of the fundus glands, having granules which yield pepsin to the gastric juice; but their granules are not quite identical in appearance with those of the principal cells of the fundus glands, and are less distinct. The cells of the secreting tubules are of a columnar or cubical shape, and in the fresh condition have a granular appearance; they are quite unlike the clear epithelium of the surface and ducts, which is formed, as elsewhere, of long tapering cells, the outer part of which is filled with mucigen.

At the pylorus itself the gastric glands, which are of the same type as those of the pyloric canal, become considerably lengthened and enlarged, and are continued into the submucous tissue, the muscularis mucosæ being here deficient; they thus present transitions to the glands of Brünner, which lie in the submucous tissue of the duodenum (fig. 472).

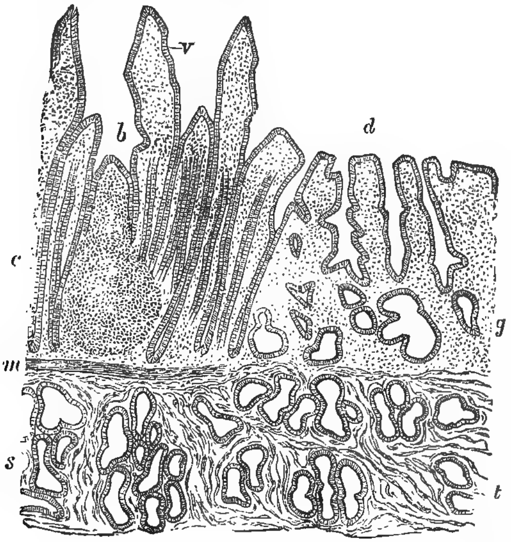


FIG. 472.—SECTION THROUGH THE PYLORUS, INCLUDING THE COMMENCEMENT OF THE DUODENUM. (Klein.)

v, villi of duodenum; *b*, apex of a lymphoid nodule; *c*, crypts of Lieberkühn; *s*, secreting tubules of Brünner's glands; *d*, ducts of pyloric glands of the stomach; *g*, tubes of these glands in mucous membrane; *t*, deeper lying tubes in submucosa, corresponding to secreting tubules of Brünner's glands of duodenum; *m*, muscularis mucosæ.

Scattered amongst the ordinary secreting cells of the pyloric glands, cells are seen here and there which stain with hæmatoxylin more deeply than the rest, and perhaps have a different function (Stöhr).

The **blood-vessels** of the stomach are very numerous; they pass to the organ along its curvatures. The arteries traverse the muscular coat, giving off branches to the capillary network of the muscular tissue; they then ramify in the submucous coat. From the arterial branches here, small tortuous arterioles pierce the muscularis mucosæ, and break up into capillaries near the bases of the glands (fig. 473). The capillary network extends between the glands to the surface, close to which it terminates in a plexus of relatively large venous capillaries which encircle the mouths of the glands. From this plexus straight venous radicles pass through the mucous membrane, pierce the muscularis mucosæ, and join a plexus of veins in the submucous coat. From these veins blood is carried away from the stomach by efferent veins, which accompany the entering arteries.

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[1] In man it is, however, only quite near the pylorus that parietal cells are altogether absent. They may even be met with in Brünner's glands of the duodenum.

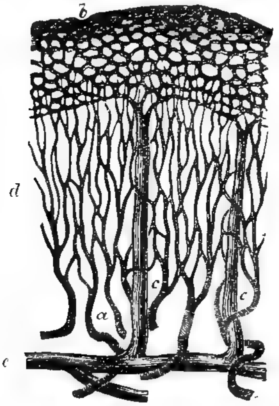

FIG. 473. PLAN OF THE BLOOD-VESSELS OF THE STOMACH. (Modified from Brinton.)

a, small arteries passing to break up into the fine capillary network, *d*, between the glands; *b*, coarser capillary network around the mouths of the glands; *c*, *c*, veins passing vertically downwards from the superficial network; *e*, larger vessels in the submucosa.

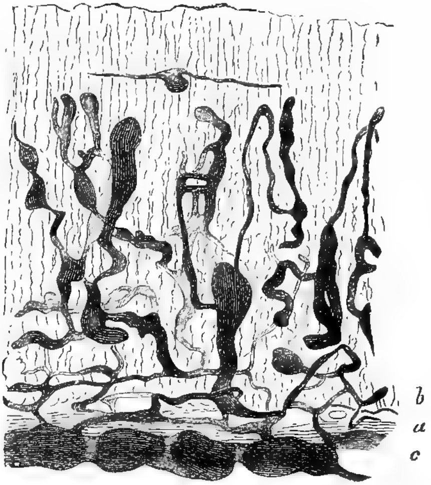

FIG. 474.—LYMPHATICS OF THE HUMAN GASTRIC MUCOUS MEMBRANE, INJECTED. (C. Lovèn.)

The tubules are only faintly indicated; *a*, muscularis mucosæ; *b*, plexus of fine vessels at base of glands; *c*, plexus of larger valved lymphatics in submucosa.

The **lymphatics** (fig. 474) arise in the mucous membrane by a plexus of large vessels dilated at intervals, and looking in sections like clefts in the interglandular tissue. From this plexus the lymph is carried into large valved vessels in the submucous coat, and, from these, efferent vessels run through the muscular coat to reach the serous membrane, underneath which they pass away from the organ. The muscular coat has its own network of lymphatic vessels. These lie between the two principal layers, and their lymph is poured into the efferent lymphatics of the organ.

The **nerves** have the same general arrangement and mode of distribution as those of the intestine (see next Lesson). They are mostly derived from the vagus, but branches of the sympathetic also pass to the organ.

LESSONS XXXII. AND XXXIII.

THE SMALL AND LARGE INTESTINE.

1. SECTIONS of the duodenum, jejunum, and ileum, vertical to the surface. The three parts of the intestine may be embedded in the same paraffin block, and the sections stained and mounted together. Choose a part of the ileum which includes a Peyer's patch. Observe the nodules of lymphoid tissue which constitute the patch and which extend into the submucous tissue. Notice the lymphoid cells in the superjacent epithelium. Notice also the sinus-like lymphatic or lacteal vessel which encircles the base of each nodule. In the duodenum study the glands of Brünner in the submucous tissue. Make a general sketch of each section under a low power and draw a villus under the high power. The general arrangement and structure of the intestinal wall is to be studied in these sections.

2. Sections parallel to the surface of the intestine, and therefore across the long axis of the villi and glands of the mucous membrane. In order to keep the sections of the villi together so that they are not lost in the mounting, it is necessary either to embed in celloidin or, if paraffin is used, to employ an adhesive method of mounting. Sketch a villus and some of the crypts of Lieberkühn.

3. To study the process of fat-absorption, kill a frog two or three days after feeding with bacon fat. Put a very small shred of the mucous membrane of the intestine into osmic acid (0·5 per cent.) and another piece into a mixture of 2 parts Müller's fluid and 1 part osmic acid solution (1 per cent.). After forty-eight hours teased preparations may be made from the osmic acid preparation, in the same manner as directed in Lesson VIII., § 1. The piece in Müller and osmic acid may be left for ten days or more in the fluid. Sections are made by the freezing method and mounted in glycerine or from paraffin and mounted in dammar.

4. Sections of small intestine the blood-vessels of which have been injected. Sketch the arrangement of the vessels of a villus.

5. From a piece of intestine, which has been stained with chloride of gold, tear off broad strips of the longitudinal muscular coat, and mount them in glycerine. It will generally be found that portions of the nervous plexus of Auerbach remain adherent to the strips, and the plexus can in this way be studied.

From the remainder of the piece of intestine tear off with forceps the fibres of the circular muscular layer on the one side, and the mucous membrane on the other side, so as to leave only the submucous tissue and the muscularis mucosæ, which is to be mounted flat in glycerine; it contains the plexus of Meissner. Sketch a small portion of each plexus under a high power. The plexuses can also be shown by the methylene-blue method and the reduced silver method of Cajal (see Appendix).

6. Sections of the large intestine, perpendicular to the surface. Sketch under a low power.

7. Sections of the mucous membrane of the large intestine parallel to the surface, and therefore across the glands. Sketch some of the glands and the interglandular tissue under a high power.

8. The arrangement of the blood-vessels of the large intestine is studied in sections of the injected organ.

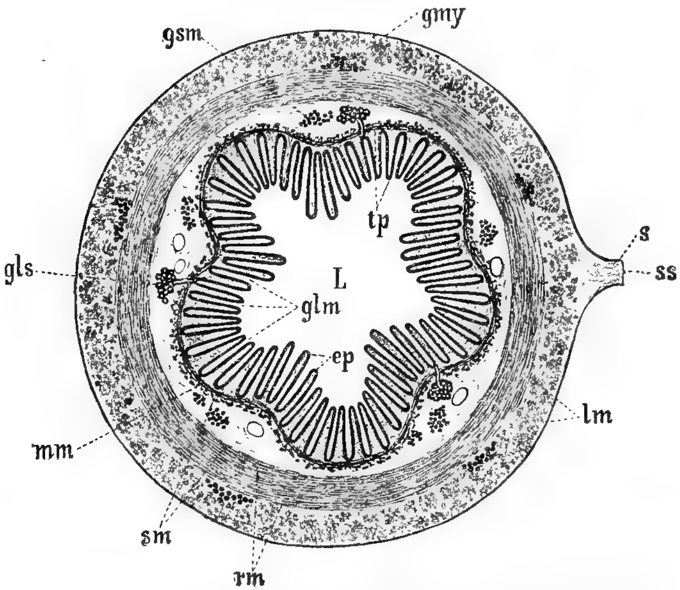

FIG. 475.—DIAGRAM OF SECTION OF ALIMENTARY TUBE. (Sobotta.)

L, lumen; *glm*, glands of mucous membrane; *ep*, epithelium; *gls*, glands in submucosa; *mm*, muscularis mucosa; *sm*, submucous coat; *rm*, circular muscular layer; *lm*, longitudinal muscular layer; *s*, serous coat; *ss*, mesentery; *gmy*, ganglion of plexus myentericus; *gsm*, ganglion of plexus submucosus.

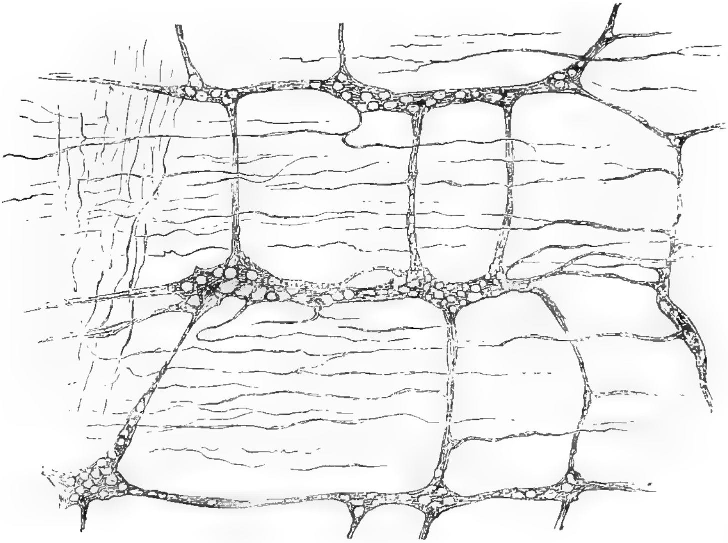

FIG. 476.—AUERBACH'S PLEXUS, FROM THE MUSCULAR COAT OF THE INTESTINE. (Cadiat.)

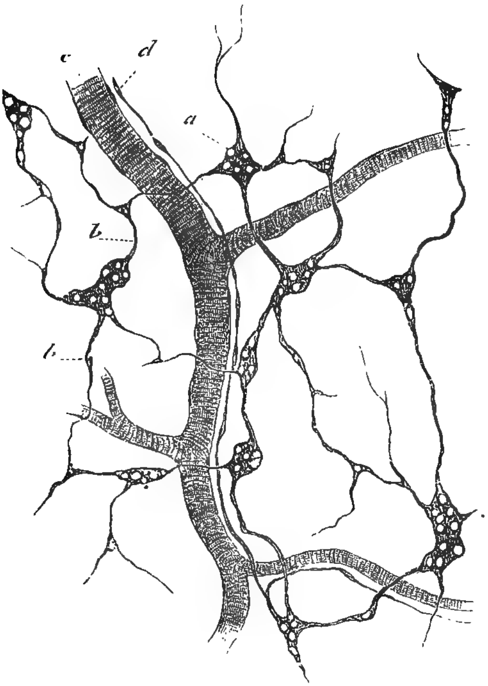

FIG. 477.—MEISSNER'S PLEXUS FROM THE SUBMUCOUS COAT. (Cadiat.) *a*, ganglion; *b*, *b*, nervous cords; *c*, a blood-vessel; *d*, an entering sympathetic nerve.

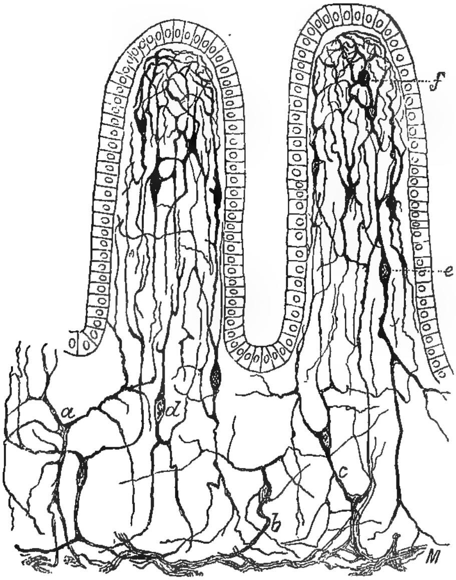

FIG. 478.—NERVES OF THE MUCOUS MEMBRANE OF THE SMALL INTESTINE. (Cajal.) *M*, part of Meissner's plexus; *a-f*, small cells and nerve-fibres in the tissue of the mucous membrane and villi.

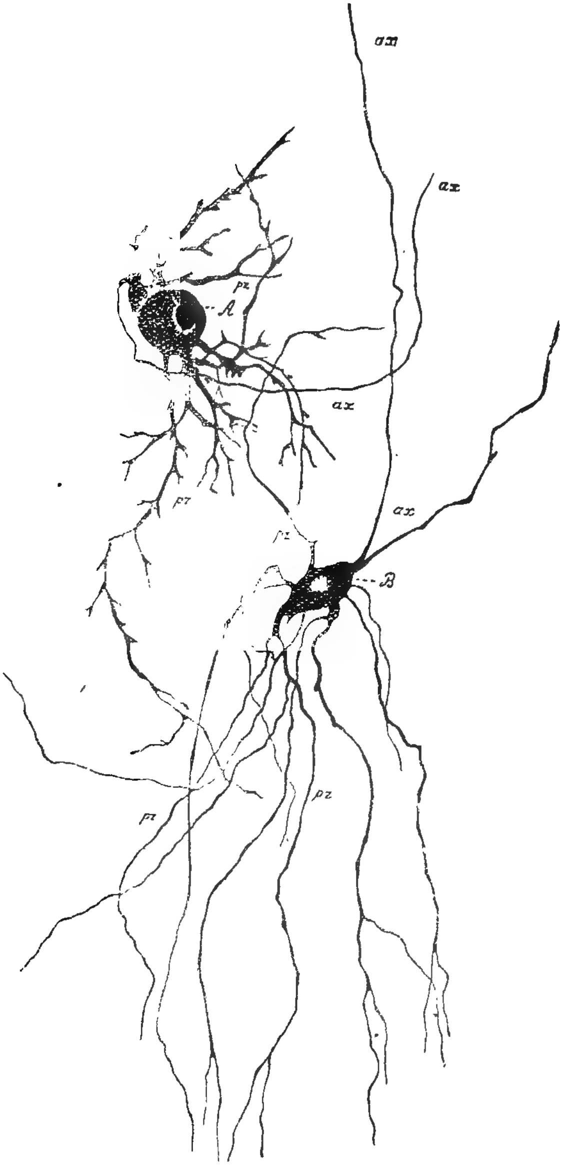

FIG. 479.—TYPICAL NERVE-CELLS FROM ENTERIC GANGLIA. (Dogiel.)
A, cell with numerous minute ramified dendrons; *B*, cell with numerous almost unbranched axon-like dendrons; *ax*, axons; *pz*, dendrons.

THE SMALL INTESTINE.

The wall of the **small intestine** consists of four coats (fig. 475).

The *serous coat* is complete except over part of the duodenum. It leaves the intestine at the line of attachment of the mesentery, between the folds of which the blood- and lymph-vessels and nerves pass to and from the organ.

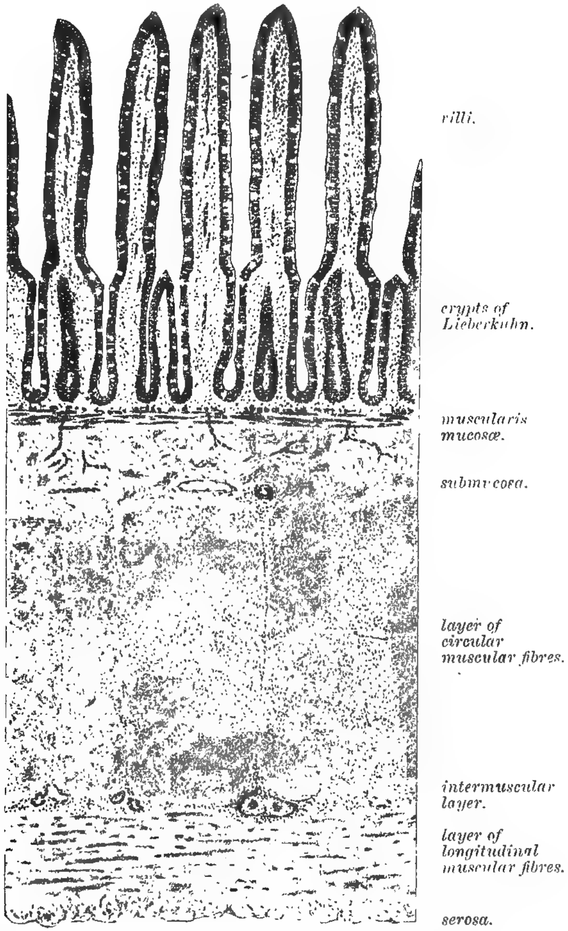

Fig. 480. – Section of the small intestine (jejunum) of cat. Magnified about 40 diameters.

The *muscular coat* is composed of two layers of muscular tissue, an outer longitudinal and an inner circular. Between them lies a network of lymphatic vessels, and also the close ganglionated plexus of non-medullated nerve-fibres known as the *plexus myentericus* of Auerbach. The ganglia of this plexus may sometimes be seen in vertical sections of the intestinal wall (figs. 480, 483), but the plexus, like the one in the submucous coat immediately to be described, can only be properly displayed in preparations made by special methods (fig. 476).

The *submucous coat* is, like that of the stomach, composed of loose areolar tissue. In it the blood-vessels and lacteals ramify before entering or after leaving the mucous membrane. It contains a ganglionated plexus of nerve-fibres—the *plexus of Meissner*—which is finer than that of Auerbach and has fewer ganglion cells (fig. 477). Its branches are chiefly supplied to the muscular fibres of the mucous membrane, but also to the glands and villi (fig. 478).

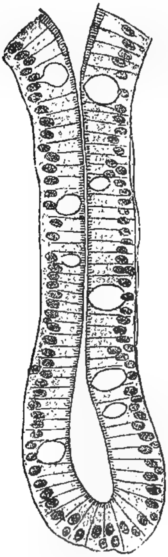

FIG. 481.

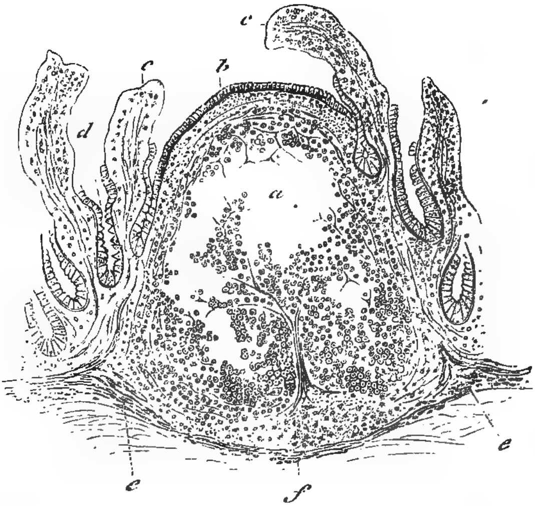

FIG. 482.

FIG. 481.—A CRYPT OF LIEBERKÜHN FROM THE HUMAN INTESTINE. (Flemming.)

FIG. 482.—SECTION OF THE ILEUM THROUGH A LYMPHOID NODULE. (Cadiat.)
a, middle of the nodule with the lymphoid tissue partly fallen away from the section; *b*, epithelium of the intestine; *c*, villi: the epithelium is partly broken away; *d*, crypts of Lieberkühn; *e*, *f*, muscularis mucosæ.

These "enteric" ganglionated plexuses contain two kinds of nerve-cell (fig. 479). One kind has a number of much branched dendrons easily distinguishable from the axon; the other kind is characterised by the presence of a number of processes very little branched and hardly distinguishable from one another. This last type of cell is the only one found in Meissner's plexus.

The *mucous membrane* is bounded next to the submucous coat by a double layer of plain muscular fibres (*muscularis mucosæ*). Bundles from this pass inwards through the membrane towards the inner surface and penetrate also into the villi. The mucous membrane proper is pervaded with simple tubular glands—the *crypts of Lieberkühn* (figs. 480, 481, 483)—which are lined throughout by a columnar epithelium, with scattered goblet-cells, like that which covers the general surface and the villi. At the fundus of each crypt are a few cells containing well-marked granules (Paneth). The cells of the glands show frequent evidences of karyokinesis; it is stated that the epithelium of the general surface becomes regenerated

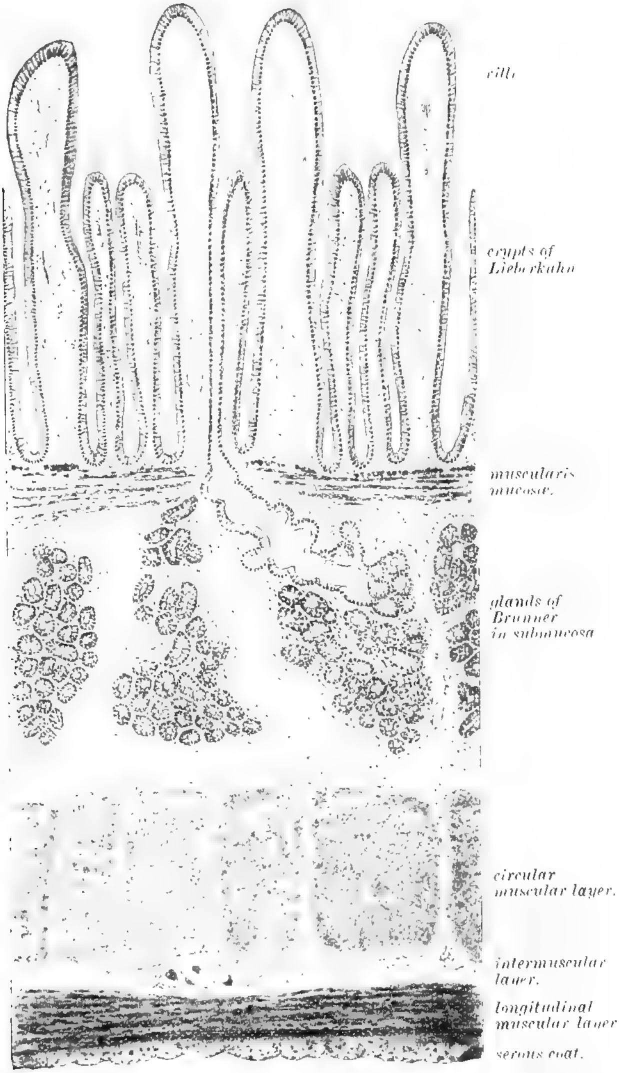

FIG. 483.—SECTION OF DUODENUM OF CAT, SHOWING BRUNNER'S GLANDS. Magnified about 60 diameters.

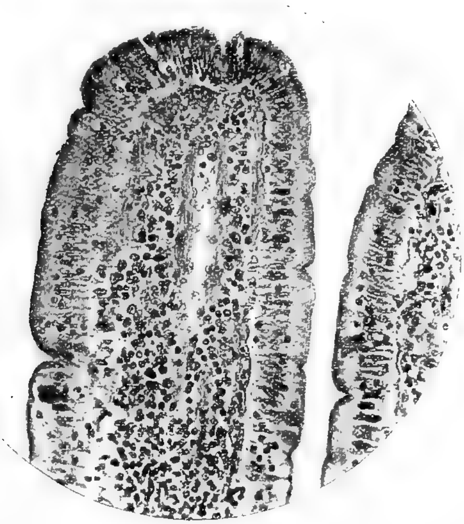

FIG. 484.—LONGITUDINAL SECTION OF A VILLUS: MAN. Magnified 200 diameters. (From a preparation by Prof. Martin Heidenhain.)

At one part the lacteal is cut longitudinally. Some leucocytes are seen within it: others are observable between the columnar epithelium-cells of the surface and many occupy the interstices of the reticular tissue.

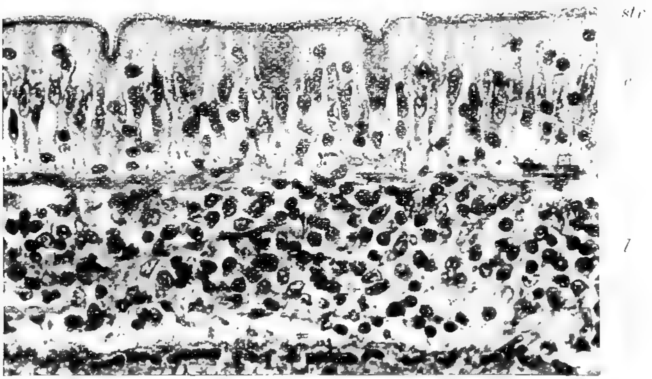

FIG. 485. PART OF THE WALL OF THE VILLUS SHOWN IN FIG. 484. Magnified 400 diameters.

c, columnar epithelium-cells; leucocytes are seen between them; *str*, their striated border; *l*, lymphoid tissue of villus. One or two goblet-cells are seen between the columnar cells.

from them (Bizzozero). The mucous membrane between the glands is mainly composed of reticular tissue, which contains here and there nodules of lymphoid tissue. These nodules constitute when they occur singly the

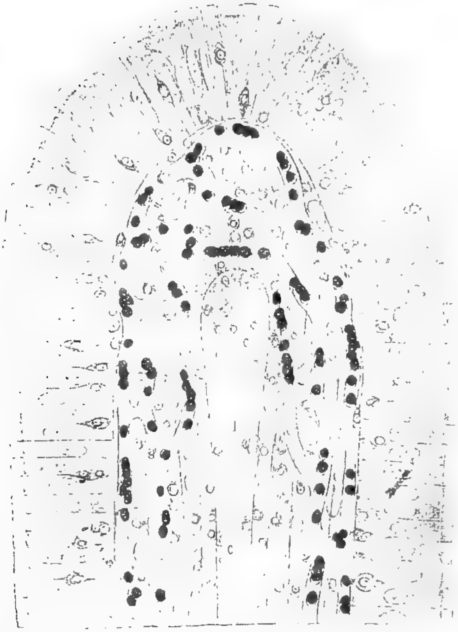

FIG. 486.—LONGITUDINAL SECTION OF A VILLUS FROM A RAT KILLED THREE HOURS AFTER FEEDING WITH BREAD AND WATER.

The columnar epithelium shows numerous lymph-corpuscles between the cells ; *l*, lacteal, containing lymph-corpuscles ; *c*, some partly disintegrated.

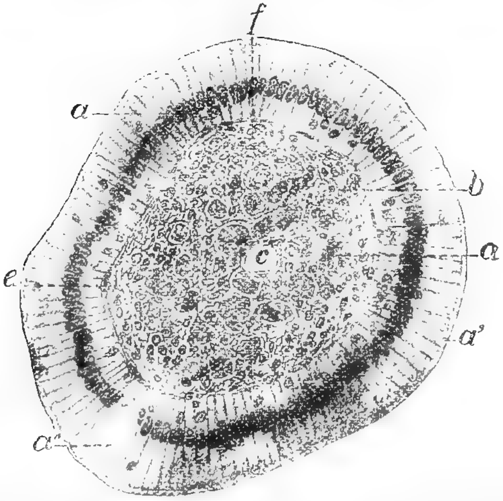

FIG. 487.—TRANSVERSE SECTION OF A VILLUS OF FIG. (Trautmann.)

a, epithelium ; *a′*, striated border ; *a″*, goblet-cell ; *b*, lymphoid tissue ; *c*, small central lacteal ; *e*, plain muscle-fibres cut transversely ; *f*, section of arteriole.

so-called *solitary glands* of the intestine (fig. 482), and when aggregated together form the *agminated glands* or *patches of Peyer* (fig. 491). The latter occur chiefly in the ileum.

The **glands of Brünner**, which have been already noticed (p. 337), occur in the duodenum. They are small tubulo-racemose glands of serous character, situated in the submucosa (fig. 483); they send their ducts to the inner surface of the mucous membrane either between the crypts of Lieberkühn or into them.

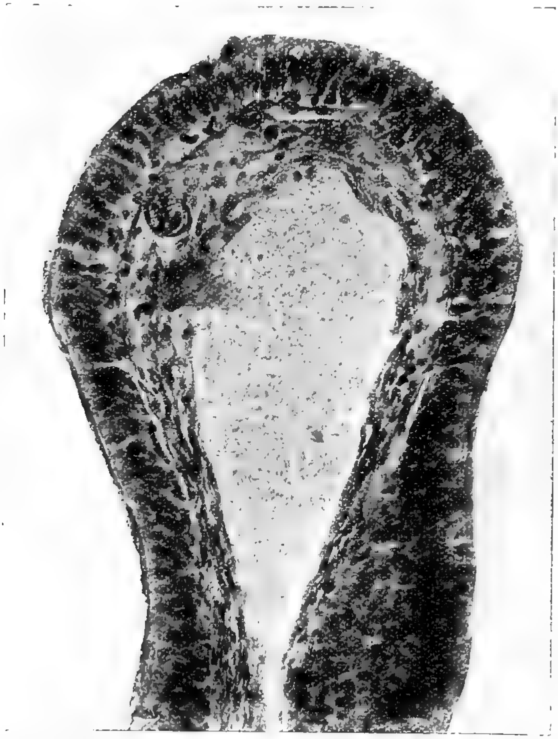

FIG. 488.—LACTEAL WITHIN VILLUS-LIKE FOLD OF THE MUCOUS MEMBRANE OF SMALL INTESTINE OF FROG. Magnified 200 diameters.

The lacteal is distended with chyle in which three or four leucocytes in various stages of disintegration are seen.

The **villi** with which the whole of the inner surface of the small intestine is closely beset are clavate or finger-shaped projections of the mucous membrane, and are composed, like that, of reticular tissue covered with columnar epithelium (figs. 484 to 488). The characters of this epithelium have already been described (Lesson VIII.). Between and at the base of the epithelium-cells many lymph-corpuscles occur, as well as in the meshes of the reticular tissue. The epithelium rests upon a basement-membrane.

In the middle of the villus is a lymphatic or lacteal vessel which may be somewhat enlarged near its commencement; the enlargement is replaced in some animals by a network of vessels. Surrounding the lacteal are small bundles of plain muscular tissue prolonged from the muscularis mucosæ.

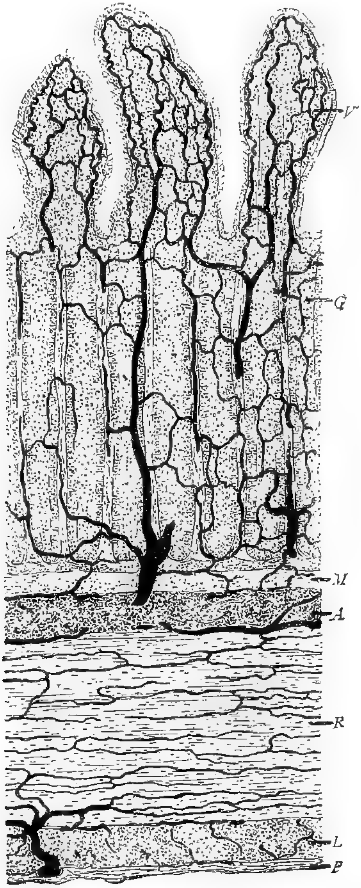

Fig. 489.—Small intestine (vertical transverse section), with the blood-vessels injected. (Heitzmann.)

V, a villus; *G*, glands of Lieberkuhn; *M*, muscularis mucosæ; *A*, areolar coat; *R*, circular muscular coat; *L*, longitudinal muscular coat; *P*, peritoneal coat.

The network of blood-capillaries (figs. 489, 490) lies for the most part quite near the surface under the basement-membrane; it is supplied with blood by a small artery which joins the capillary network at the base of the villus; the corresponding vein generally arises near the free end of the villus.

The *lymphatics* (lacteals) of the mucous membrane (fig. 491), after receiving the central lacteals of the villi, pour their contents into a plexus of large valved lymphatics which lie in the submucous tissue and form sinuses around the bases of the lymphoid nodules (fig. 340, p. 243). From the submucous tissue efferent vessels pass through the muscular coat, receiving the lymph from an intramuscular plexus of lymphatics, and are conveyed away between the layers of the mesentery.

Absorption of fat.—In order to study the process of fat transference in the intestine, it is convenient to stain the fat with osmic acid, which colours it black. It can then be observed that in animals which have been fed with food containing fat, particles of fat are present (1) in comparatively large globules in the outer part of the columnar epithelium-cells, but in the form of much smaller globules in their deeper part (in the free border of the cell fat is entirely absent); (2) in fine granules in the interstitial tissue of the villus, but often confined to the amœboid leucocytes, which abound in this tissue; (3) in fine granules within the central lacteal of the villus. The leucocytes are present not only in the reticular tissue of the villus, but also in considerable numbers between and at the base of the epithelium cells (figs. 485, 486); and they can also be seen in thin sections from bichromate-osmic preparations within the commencing lacteal; in the last situation they are undergoing disintegration (figs. 486, 488, 492).

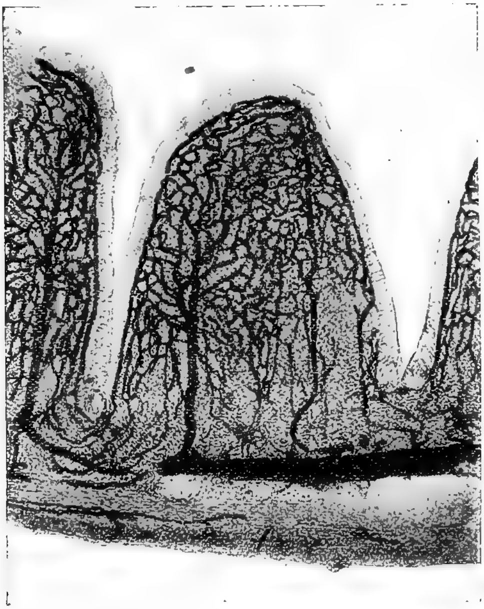

FIG. 490.—VILLUS OF RAT WITH BLOOD-VESSELS INJECTED. Photograph. Magnified 210 diameters.

Since the leucocytes are amœboid, it is probable from these facts that the mechanism of fat-absorption consists of the following processes—viz. (1) accumulation of fat in the columnar epithelium-cells of the surface;

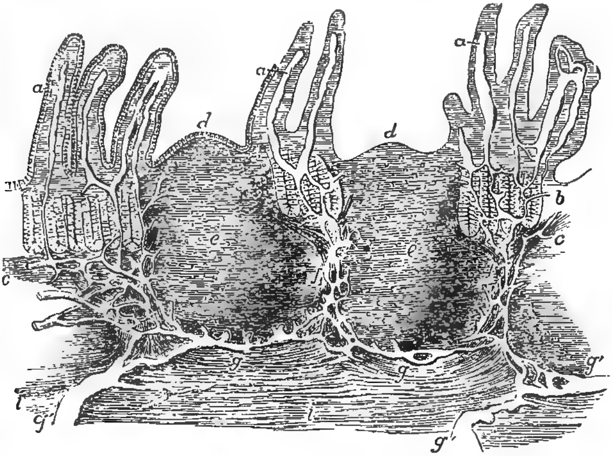

FIG. 491.—VERTICAL SECTION OF A PORTION OF A PEYER'S PATCH WITH THE LACTEAL VESSELS INJECTED. Magnified 32 diameters. (Frey.)

The specimen is from the lower part of the ileum; *a*, villi, with their lacteals left white; *b*, some of the tubular glands; *c*, the muscular layer of the mucous membrane; *d*, cupola or projecting part of nodule; *e*, central part; *f*, the reticulated lacteal vessels occupying the lymphoid tissue between the nodules, joined above by the lacteals from the villi and mucous surface, and passing below into *g*, the sinus-like lacteals under the nodules, which again pass into the large efferent lacteals, *g'*; *i*, part of the muscular coat.

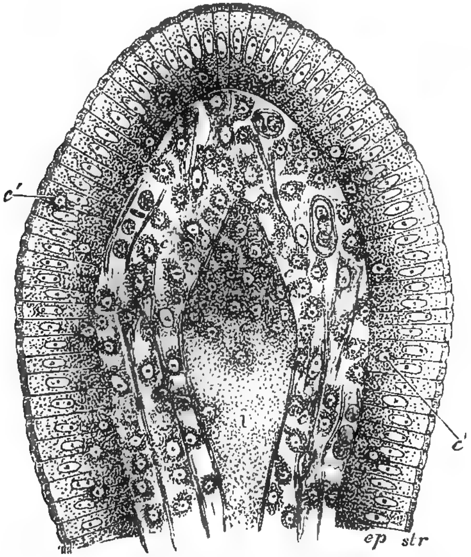

FIG. 492.—SECTION OF THE VILLUS OF A RAT KILLED DURING FAT-ABSORPTION

ep, epithelium; ***str***, striated border; ***c***, leucocytes; *c'*, leucocytes in the epithelium *l*, central lacteal containing chyle and disintegrating leucocytes.

(2) ejection of fat-granules from the epithelium into the intercellular spaces; (3) ingestion of fat by leucocytes, these taking it up after it has passed out of the epithelium-cells; (4) migration of leucocytes carrying fat-particles through the tissue of the villus and into the central lacteal; (5) disintegration and solution of the immigrated leucocytes, with setting free of their contents. Fat-particles are never seen in the striated border of the columnar cell: the fat of the food first becomes saponified by the action of the digestive juices, and reaches the epithelium-cell in the form of dissolved soap; the fat which is seen and stained by osmic acid within the cells has become re-formed by a process of synthesis.

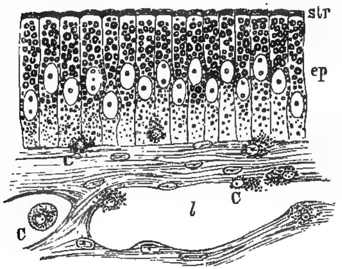

FIG. 493.—MUCOUS MEMBRANE OF FROG'S INTESTINE DURING FAT-ABSORPTION.

ep, epithelium; *str*, striated border; *c*, leucocytes; *l*, lacteal. The fat particles have been stained black by osmic acid.

In young sucking animals (puppy, kitten) the fat which is undergoing absorption is sometimes seen not only in epithelium-cells and leucocytes, but also in the form of streaks, stained black by osmic acid, in the interstices of the reticular tissue of the villi.

The migration of leucocytes into the lacteals of the villi is not a special feature of absorption of fat, but occurs also when absorption of other matters is proceeding (fig. 485); the transference of fat-particles is therefore merely an incident in the general phenomenon of migration which accompanies the process of absorption.

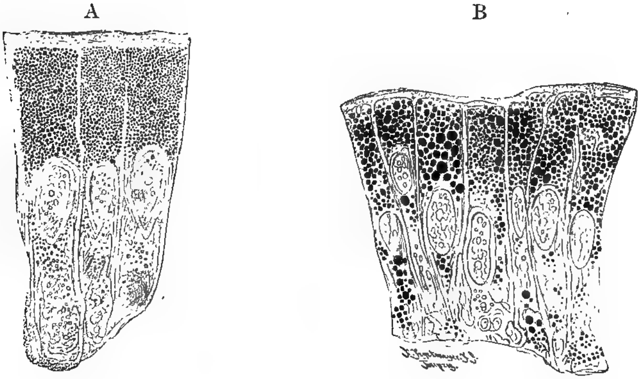

FIG. 494.—TWO STAGES IN THE DEPOSITION OF FAT IN THE INTESTINAL EPITHELIUM OF THE FROG. (Krehl.)

In *A* the fat is in very fine particles; in *B* most of it is aggregated into distinct globules. The black staining is due to the action of osmic acid.

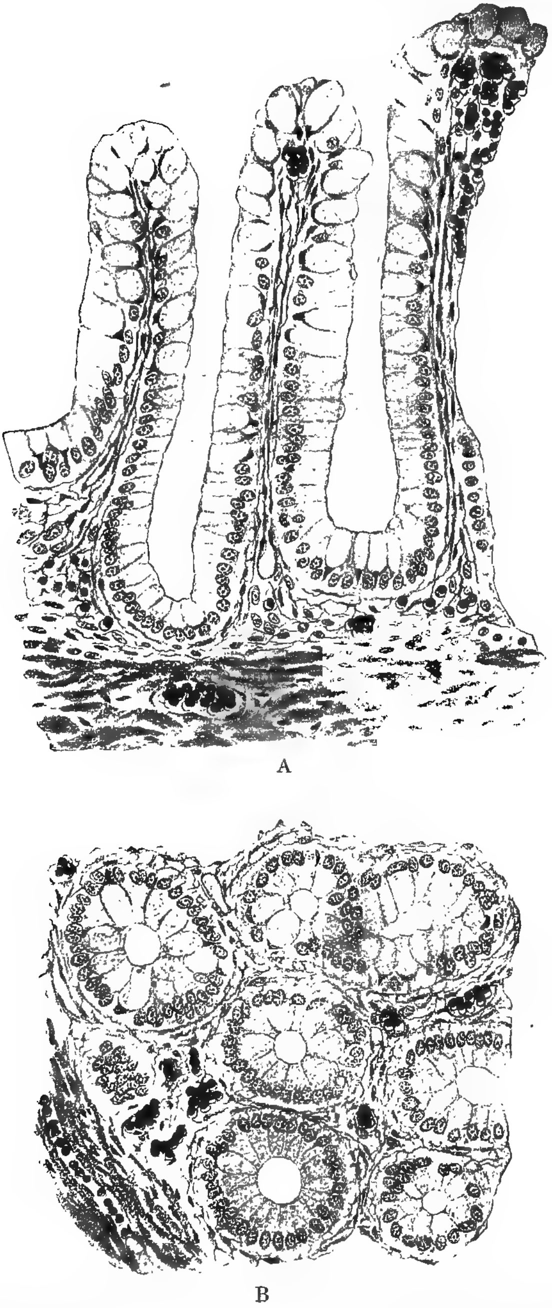

FIG. 495.—GLANDS OF THE LARGE INTESTINE OF CHILD. 300 diameters.
A, in longitudinal section; *B*, in transverse section.

LARGE INTESTINE.

The **large intestine** has the usual four coats, except near its termination, where the serous coat is absent. In man the *muscular coat* is peculiar in the fact that along the cæcum and colon the longitudinal muscular fibres are gathered up into three thickened bands which produce puckerings in the wall of the gut.

The *mucous membrane* of the large intestine is beset with simple tubular glands somewhat resembling the crypts of Lieberkühn of the small intestine, and lined by columnar epithelium similar to that of the inner surface of the small gut: but containing many more mucus-secreting or goblet cells (fig. 495). The blind extremity of each gland is usually slightly dilated. These glands of the large intestine are not strictly homologous with the crypts of the small intestine, for whereas the latter are developed as depressions in the general surface between the villi, the glands of the large intestine are formed by the growing together of villus-like projections of the surface. The interglandular tissue is a reticular tissue and is beset here and there with solitary glands, especially in the cæcum. The mucous membrane of the vermiform appendix (fig. 496) is in great part of its extent packed full of lymphoid nodules.

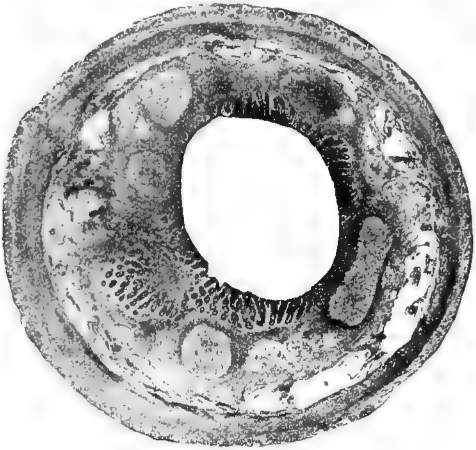

FIG. 496.—TRANSVERSE SECTION OF VERMIFORM APPENDIX. (G. Mann.)

The arrangement of the blood-vessels and lymphatics in the large intestine is like that in the stomach. The nerves of the large intestine also resemble those of the stomach and small intestine in their mode of distribution.

At the lower end of the rectum the circular muscular fibres of the gut become thickened a little above the anus to form the *internal sphincter* muscle. In the anal region there are a number of compound racemose mucous glands opening on the surface of the mucous membrane (*anal glands*). The anal orifice has a lining of stratified epithelium continuous with that of the skin.

LESSONS XXXIV. AND XXXV.

THE LIVER AND PANCREAS.

1. Sections of liver are to be studied carefully. They may be stained with eosin and hæmatoxylin, or by iron-hæmatoxylin. Sketch the general arrangement of the cells in a lobule under the low power; and under the high power make detailed drawings of some of the hepatic cells and also of a portal canal. If from the pig, the outlines of the lobules are observed to be well marked off by connective tissue.

Notice that the hepatic cells are in intimate contact with the blood-capillaries or sinuses. Some cells are occasionally found to contain red blood-corpuscles; many contain eosinophil granules. Notice in the sinus-like capillaries the partly detached endothelial-cells (stellate cells of Kupffer). These, which are phagocytic, frequently contain erythrocytes, which appear to be in process of destruction.

2. To observe glycogen within the liver-cells, kill a rabbit or rat (preferably about six hours after a meal of carrot), and at once throw a thin piece of the liver into 96 per cent. alcohol. When well hardened the piece may be embedded in paraffin in the usual way, or sections may be cut with the free hand without embedding. Some of the sections so obtained are to be treated with a 1 per cent. solution of iodine in potassium iodide for five minutes; they may then be mounted in a nearly saturated solution of potassium acetate, the cover-glass being cemented with gold size, and can thus be kept for a time, but they will eventually fade.

3. Presence of iron. In sections of alcohol-hardened liver treated first with potassium ferrocyanide solution and then with hydrochloric acid and alcohol (1 to 10), then passed through absolute alcohol into xylol, and finally mounted in dammar, many of the pigment granules will be stained blue (Prussian blue). Another method is to place the sections in an aqueous solution of hæmatoxylin (1 to 300), with or without previous treatment with alcohol containing 10 parts per cent. hydrochloric acid (to set free organically combined iron), after which they are mounted in the ordinary way (Macallum).

4. Injected preparations. Study with the low power a thick section to show the general arrangement of the blood-vessels, and with a high power a very thin section, which may be lightly stained with hæmatoxylin. In this the injection will be seen to have penetrated into canaliculi within the liver-cells themselves. Make a general sketch of a lobule under the low power and draw a small part of the network of blood-vessels and intracellular canaliculi under the high power.

5. Take a small piece of liver which has been several weeks in 2 per cent. bichromate of potassium solution or Müller's fluid and plunge it in 1 per cent. nitrate of silver solution, changing the fluid after half an hour. Leave the piece of liver in the silver solution overnight. It may then be transferred to alcohol, and after complete dehydration embedded and cut in paraffin in the usual way and the sections mounted in dammar. In many parts of such sections the bile-canaliculi are stained.

They can also be brought to view (at the periphery of the lobules) by injection with solution of Berlin blue from the hepatic duct; or, throughout the whole of the lobule, by injecting about 60 c.c. of saturated sulphindigotate of soda solution, in three successive portions at intervals of half an hour, into the blood-vessels of an anæsthetised cat or rabbit. Two hours after the last injection the animal is killed, and the blood-vessels washed out with saturated solution of potassium chloride. The organ is then fixed with absolute alcohol. The chromate of silver method is easier and surer than the injection methods.

6. Tease a piece of fresh liver in serum or salt solution for the study of the appearance of the hepatic cells in the recent or living condition.

7. Stained sections of pancreas from a gland which has been hardened in alcohol, or in formol followed by alcohol. The sections may be stained with eosin and hæmatoxylin or with iron-hæmatoxylin. Notice the islets of Langerhans between the alveoli; they are most numerous near the splenic end of the pancreas.
Make sketches under both low and high power.

8. Tease a small piece of fresh pancreas in serum or salt solution or in dilute glycerine after treatment with osmic acid. Notice the granules in the alveolar cells, chiefly accumulated in the half of the cell which is nearest the lumen of the alveolus, leaving the outer zone of the cell clear.
Sketch a small portion of an alveolus under a high power.

9. The endings of the ducts in the alveoli, and the termination of nerve-fibres amongst the gland-cells may be seen in preparations made by the Golgi method.

THE LIVER.

The **liver** is a solid glandular organ, made up of the *hepatic lobules.* These are polyhedral masses (fig. 497) about 1 mm. ($\frac{1}{25}$ inch) in diameter, composed of cells, and separated from one another by connective tissue. In some animals, *e.g.* the pig, this separation is complete, and each lobule is isolated, but in man and most animals it is incomplete. There is also a layer of connective tissue underneath the serous covering of the liver, forming an external capsule to the organ. Each lobule is penetrated by a fine network of reticular tissue which helps to support the columns of cells within the lobule (fig. 498).

The afferent **blood-vessels** of the liver (portal vein and hepatic artery) enter it on its under surface, where also the bile-duct passes away from the gland. The branches of these three vessels accompany one another in their course through the organ, and are enclosed by loose connective tissue (*capsule of Glisson*), in which are lymphatic vessels, the whole being termed a *portal canal* (fig. 499). The smaller branches of the vessels penetrate to the intervals between the hepatic lobules, and are known as the interlobular branches. The blood leaves the liver at the back of the organ by the hepatic veins; the branches of these run through the gland unaccompanied by other vessels (except lymphatics) and can also be traced to the lobules, from each of which they receive a minute branch (central or intralobular vein) which passes from the centre of the lobule, and opens directly into the (sublobular) branch of the hepatic vein.

Lobules.—Each lobule is a mass of cells pierced everywhere with a network of sinus-like blood-vessels, the so-called hepatic capillaries (figs. 497, 500). These at the periphery of the lobule receive blood from the interlobular branches of the portal vein (*p*), and converging to the centre of the lobule, unite to form the intralobular branch of the hepatic vein (central vein of lobule). The interlobular branches of the hepatic arteries join this network a short distance from the periphery of the lobule. The blood-capillaries are in direct

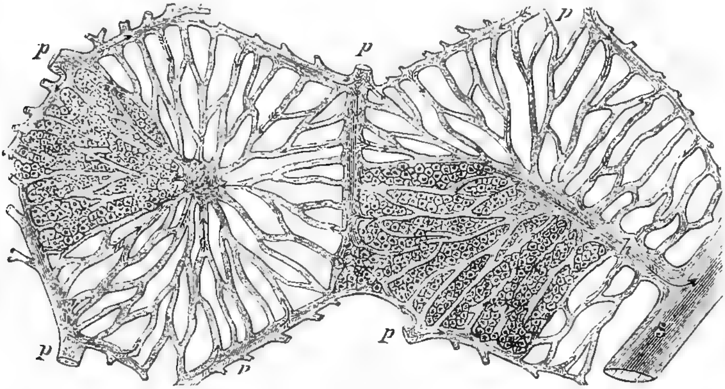

FIG. 497.—DIAGRAMMATIC REPRESENTATION OF TWO HEPATIC LOBULES.

The left-hand lobule is represented with the intralobular vein cut across; in the right-hand one the section takes the course of the intralobular vein. *p*, interlobular branches of the portal vein; ***h***, intralobular branches of the hepatic veins; *s*, sublobular vein; ***c***, capillaries of the lobules. The arrows indicate the direction of the course of the blood. The liver-cells are only represented in one part of each lobule.

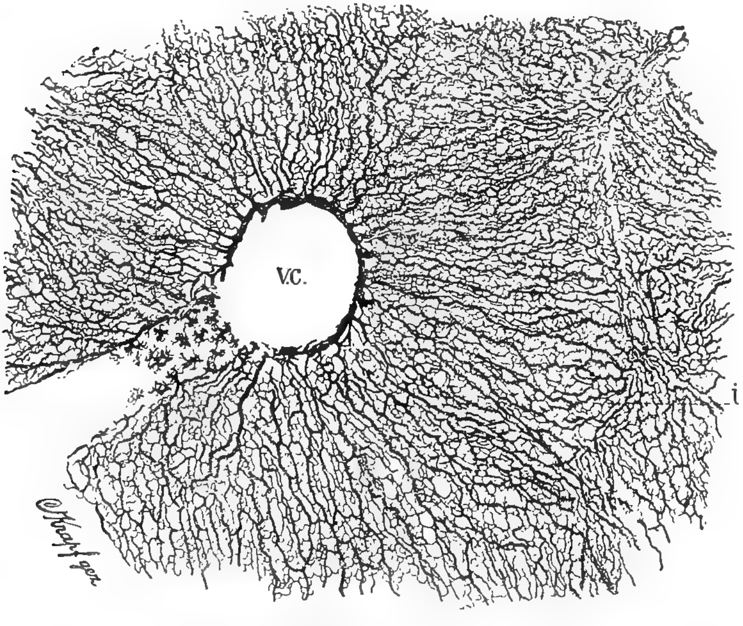

FIG. 498.—RETICULUM OF A LIVER-LOBULE. (Oppel.)

V.C., central vein; *i*, interlobular interval.

contact with the liver-cells; their endothelium is deficient, for artificial injections come in actual contact with the cells and even pass into

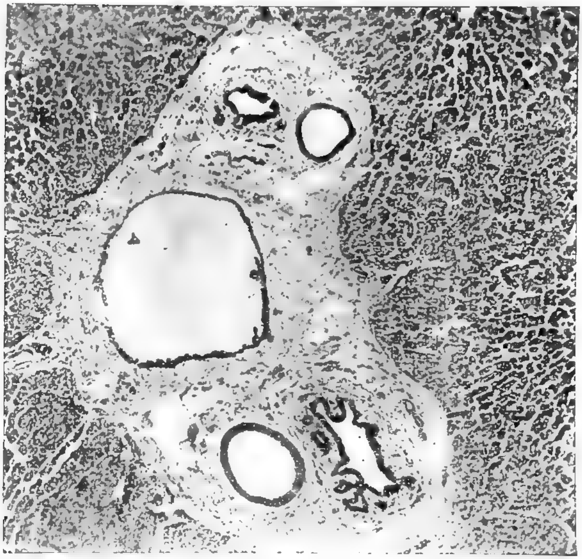

FIG. 499.—SECTION OF A PORTAL CANAL: DOG. Photograph. Magnified about 50 diameters.

The large vessel is a branch of the portal vein; the irregular tubes are sections of branches of the hepatic duct; near them are sections of branches of the hepatic artery. All the vessels are enclosed by the connective tissue of the capsule of Glisson; in this tissue several lymphatic vessels are seen as clear spaces. The whole is surrounded by the liver-lobules.

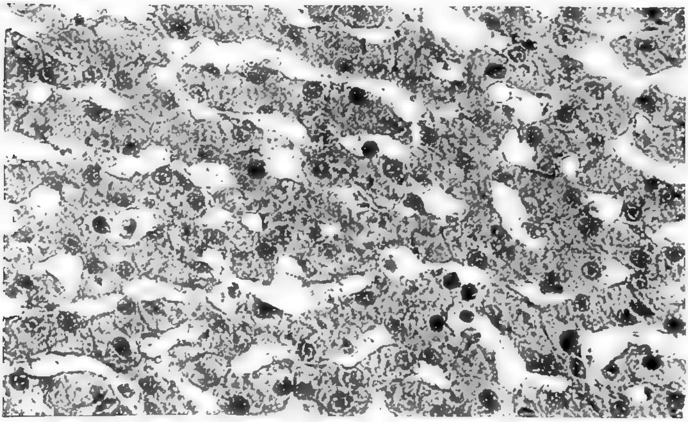

FIG. 500.—SECTION OF DOG'S LIVER, STAINED WITH HÆMATOXYLIN, SHOWING THE HEPATIC CELLS AND THE SINUS-LIKE NATURE OF THE BLOOD-CHANNELS BETWEEN THEM. Photograph. Magnified 200 diameters.

It will be observed that in most places the blood-channels are directly bounded by the liver-cells, the endothelium of the blood-sinuses being deficient.

canaliculi within their protoplasm. What remains of the endothelium of the blood-sinuses is represented by conspicuous cells which occur at intervals on the walls of the sinuses, where they lie in contact with the liver-cells. These are the *stellate cells* described by Kupffer. They are highly phagocytic, like the endothelial cells of the blood-sinuses of the spleen, and ingest erythrocytes, which can be seen within them. They also tend to take in any fine solid particles which may be injected into the blood.

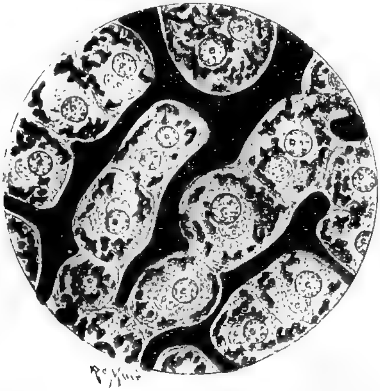

FIG. 501.—FROM A SECTION OF RABBIT'S LIVER INJECTED FROM THE PORTAL VEIN, SHOWING INTRACELLULAR CANALICULI COMMUNICATING WITH THE INTERCELLULAR BLOOD-SINUSOIDS.

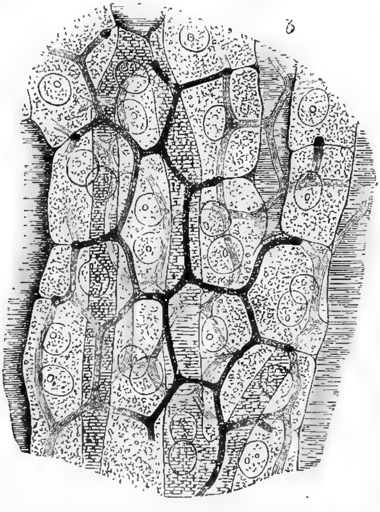

FIG. 502.—SECTION OF RABBIT'S LIVER WITH THE INTERCELLULAR NETWORK OF BILE-CANALICULI INJECTED. Highly magnified. (Hering.)

Two or three layers of cells are represented; *b*, blood-capillaries.

The **hepatic cells** (fig. 500), which everywhere lie between and surround the blood-sinuses, are polyhedral, somewhat granular-looking cells, each containing a spherical nucleus. The protoplasm of each cell is pervaded by an irregular network of canaliculi (fig. 501); these in preparations of injected liver become filled with the injection material, which has passed into them from the blood-vessels. They thus form a system of intracellular canals which receive blood-plasma directly from the vessels instead of through the lymph-spaces as is usual in most organs. Such canals were

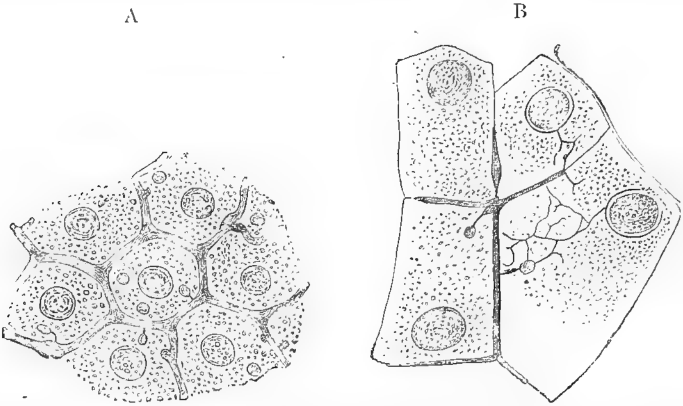

FIG. 503.—SKETCHES ILLUSTRATING THE MANNER IN WHICH BILE PASSES FROM THE HEPATIC CELLS INTO THE INTERCELLULAR BILE-CHANNELS. (R. Heidenhain after Kupffer.)

A, from liver of rabbit the bile-ducts of which had been injected backwards from the hepatic duct.

B, from liver of frog naturally injected with sulphindigotate of soda, which when transfused into the blood is excreted by the liver.

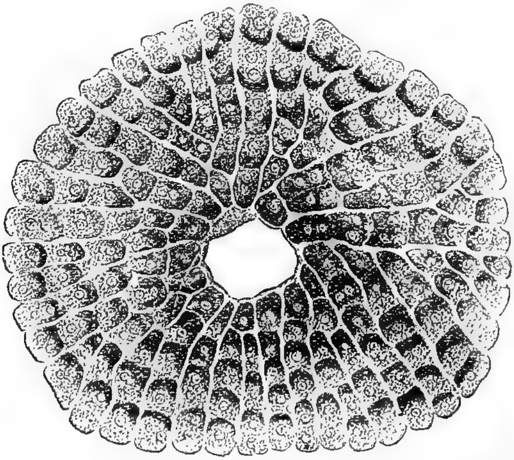

FIG. 504.—LIVER-CELLS CONTAINING GLYCOGEN. (Barfurth.)

conjectured to exist by Browicz, who showed that under certain circumstances not only hæmoglobin but whole red blood-corpuscles, and even groups of blood-corpuscles, which are in process of breaking down, are to be found in the interior of the hepatic cells. In the dog's liver both hæmoglobin and bilirubin may be found in the form of crystals within the

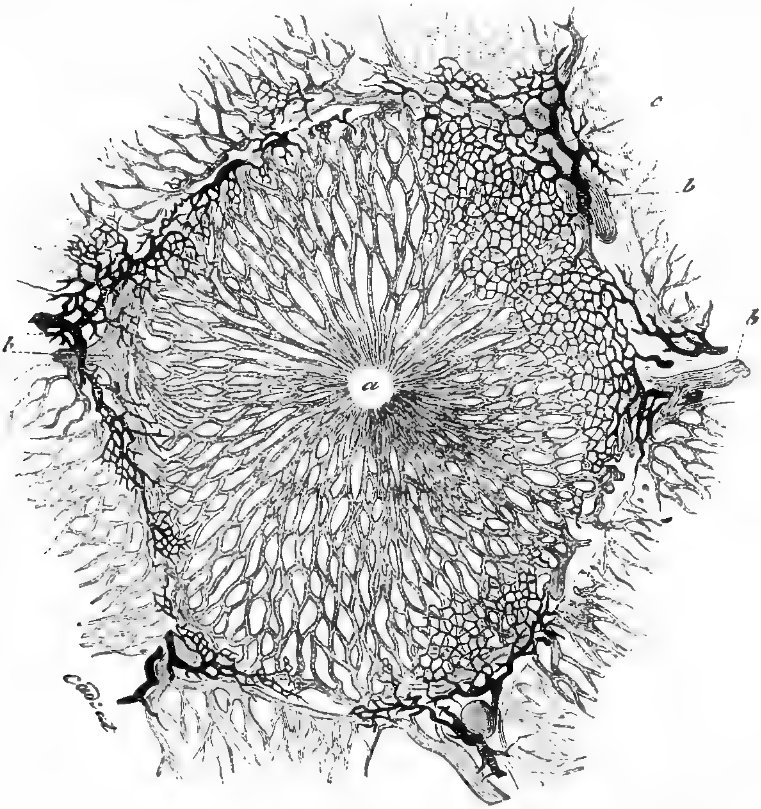

FIG. 505.—LOBULE OF RABBIT'S LIVER: VESSELS AND BILE-DUCTS INJECTED. (Cadiat.)

a, central vein; *b*, *b*, peripheral or interlobular veins; *c*, interlobular bile-duct. The liver-cells are not represented.

nuclei of the liver-cells (Browicz). Browicz' observations were confirmed by Herring and Simpson who also showed that it is possible in all animals to inject these minute canals from the blood-vessels even when a low pressure is used for injection. They are seen to contain the injection material which has been used to fill the blood-vessels in fig. 501, which is from a preparation of the rabbit's liver.

Besides these plasma-canaliculi the liver-cells may show fine, short canals which communicate with the intercellular bile-ducts (see next page); these generally commence within the cell by dilatations (secretion vacuoles) (fig. 503); probably they are not permanent structures.

After a mixed meal many of the liver-cells contain fat, and masses of glycogen can also be seen within them (fig. 504) if the liver be hardened in alcohol and treated in the manner described in section 2. The cells also contain pigment-granules, many of which are stained by potassium ferrocyanide and hydrochloric acid, or by pure hæmatoxylin (presence of iron).

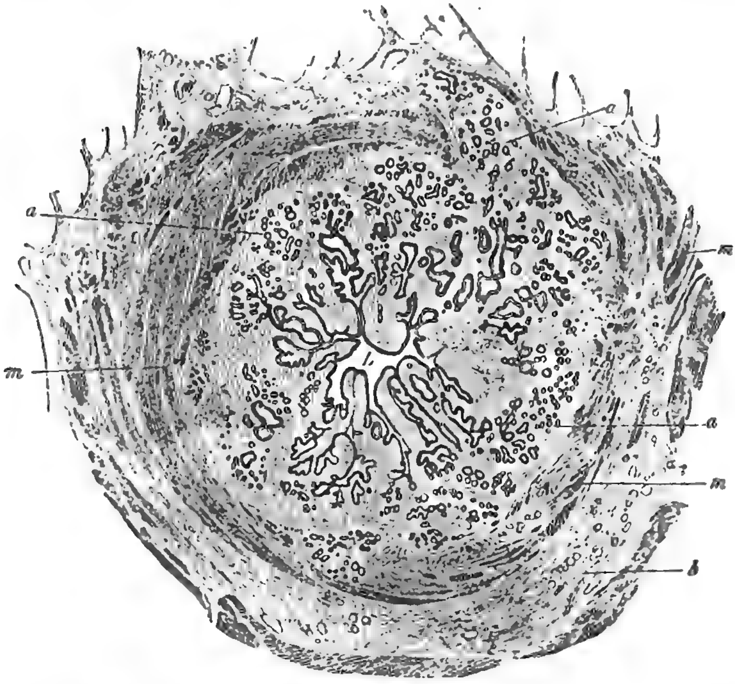

FIG. 506.—SECTION ACROSS HEPATIC DUCT: MAN. (v. Ebner.) Magnified 16 diameters. *L*, lumen of duct with orifices of numerous small glands; *a*, their alveoli; *b*, areolar tissue with vessels and a few fat-cells; *m*, plain muscle-fibres.

The iron which is in organic combination can be set free by treatment for a short time with alcohol to which 10 parts hydrochloric acid per cent. has been added.

The smallest ducts commence between the hepatic cells in the form of *intercellular bile-channels*, which lie between the adjacent sides of the cells, and receive the contents of the secretion-vacuoles above mentioned. They form what appears to be a network, the meshes of which correspond in size to the cells (fig. 502); in some cases the network is incomplete, some of the channels ending blindly. At the periphery of the lobule the intercellular channels pass into the interlobular bile-ducts (fig. 505). The bile-channels are always bounded by hepatic cells, never placed between a cell and a blood-sinus (G. Retzius).

The issuing **bile-ducts** are lined by clear columnar epithelium. Outside this is a basement-membrane, and in the larger ducts some fibrous and plain muscular tissue. Many of the large ducts are beset with small blind diverticula; the main duct has small acinous glands in its wall (fig. 506).

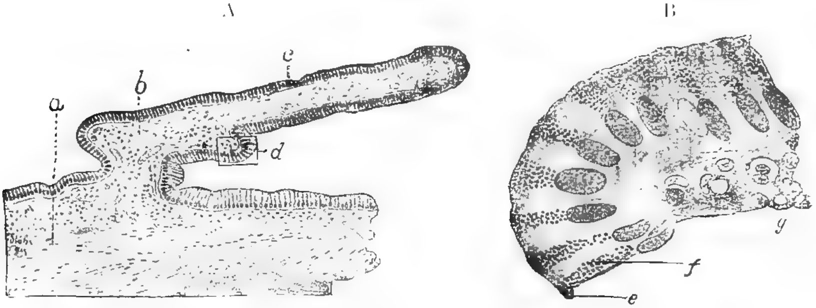

FIG. 507.—SECTIONS OF THE WALL OF THE GALL-BLADDER. (Sommer.)

A, Under a low magnifying power. *a*, muscular coat; *b*, a fold of mucous membrane; *c*, columnar epithelium; *d*, portion represented in *B* more highly magnified.

B, Magnified portion of epithelium and subjacent corium. *e*, striated border; *f*, mucigen granules in cells; *g*, blood-capillaries.

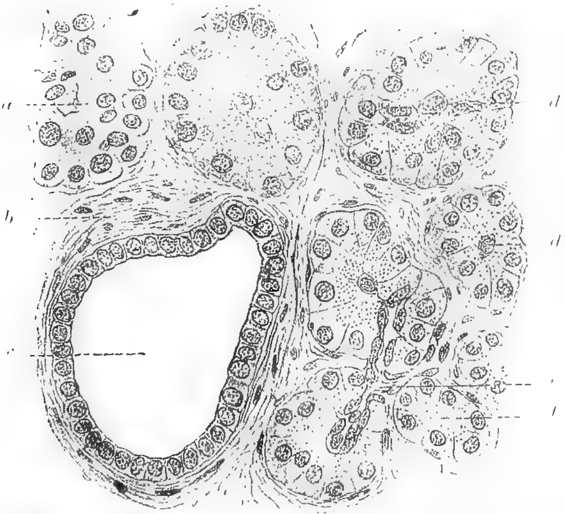

FIG. 508. SECTION OF HUMAN PANCREAS. (Bohm and v. Davidoff.) Magnified 450 diameters.

a, group of cells in interstitial tissue (? part of an islet of Langerhans); *b*, connective tissue; *c*, larger duct; *d*, *d*, alveoli with centro-acinar cells; *e*, small duct passing into alveoli; *f*, inner granular zone of alveolus.

The **gall-bladder** is in its general structure similar to the larger bile-ducts. It is lined by columnar epithelium; outside this its wall is formed of fibrous and muscular tissue. The mucous membrane is thrown into permanent reticulating folds (fig. 507), which become larger and more numerous near the neck of the gall-bladder.

The **lymphatics** of the liver were described by MacGillivray as commencing as perivascular lymphatic spaces enclosing the capillaries of the lobules. But this cannot be so, since there is no space between the liver cells and the blood in the sinus-like capillaries. All that can be positively asserted is that there are numerous lymphatics accompanying the interlobular branches of the portal vein, and others, less numerous, accompanying the tributaries of the hepatic veins, but so far as can be ascertained no direct communication exists between the two sets of lymphatics within the lobules, although they communicate freely both at the periphery of the lobules and near their exit from the liver (Herring and Simpson). Most of the liver lymph passes away by the portal lymphatics.

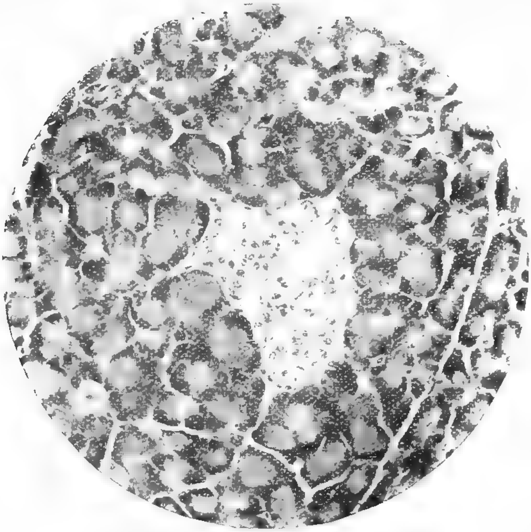

FIG. 509.—AN ISLET OF LANGERHANS IN PANCREAS OF DOG. Magnified 300 diameters.

The nerves of the liver are mostly non-medullated. They reach the organ through the sympathetic. They are distributed both to the blood-vessels and to the liver-cells.

The mode of development of the liver has already been considered (p. 222).

THE PANCREAS.

The **pancreas** is a tubulo-racemose gland, resembling the serous salivary glands so far as its general structure is concerned, but differing from them in the fact that the alveoli are longer and more tubular in character. Moreover, the connective tissue of the gland is somewhat looser, and there occur scattered throughout the glandular substance small groups of epithelium-cells unfurnished with ducts (*islets of Langerhans*) (fig. 508, *a*; fig. 509), which are supplied with a close network of large convoluted capillary vessels (fig. 510). The presence of these islets is very characteristic of the pancreas.

There are good grounds for the belief that they are concerned with the influence exerted by the pancreas on the metabolism of carbohydrates.

The islets contain two kinds of cell, distinguishable from one another by the characters of their granules. The islets are well brought out by Bensley's method of staining them, *in vivo*, with neutral red which colours them selectively. In the human pancreas there are as many as from ten to twenty islets in each milligramme of the organ, which would give about a million in the whole pancreas (Clerk).

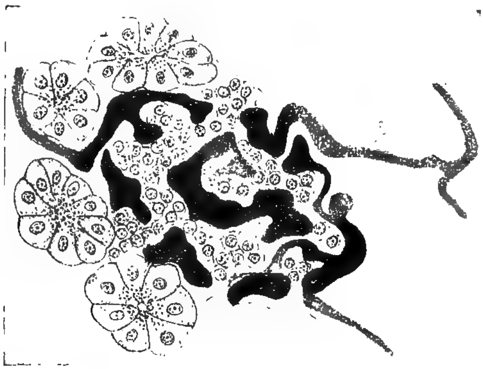

FIG. 510.—INJECTION OF BLOOD-VESSELS OF AN "ISLET" OF THE PANCREAS (Kühne and Lea.)

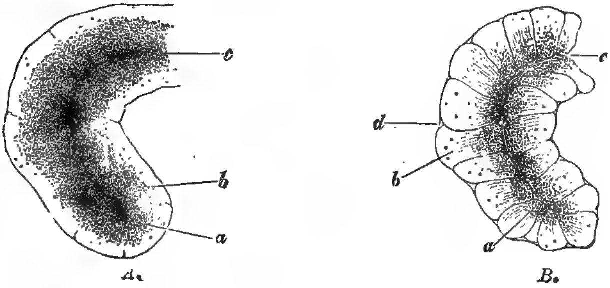

FIG. 511.—PART OF AN ALVEOLUS OF THE RABBIT'S PANCREAS. *A*, AT REST; *B*, AFTER ACTIVE SECRETION. (From Foster, after Kühne and Lea.)

a, the inner granular zone, which in *A* is larger and more closely studded with granules than in *B*, in which the granules are fewer; *b*, the outer transparent zone, small in *A*, larger in *B*, and in the latter marked with faint striæ; *c*, the lumen, very obvious in *B*, but indistinct in *A*; *d*, indentation at the junction of two cells, only distinct in *B*.

The cells which line the alveoli are columnar or polyhedral in shape. When examined in the fresh condition, or in sections stained by certain reagents (*e.g.* osmic acid), their protoplasm is seen to be filled in the inner two-thirds with granules, but the outer third is left clear or is striated (figs. 508, 509, 511, A, 512). After a period of activity the clear part of the cell becomes larger, and the granular part smaller (fig. 511, B; fig. 513). In hæmatoxylin-stained sections the outer part is coloured more deeply than the inner (fig. 509).

Pancreas cells frequently exhibit a rounded mass of mitochondria near the nucleus, which is known as the paranucleus (see fig. 8): it is probably related to the secretory activity of the cells and is not peculiar to the pancreas, although often better marked in that organ than elsewhere.

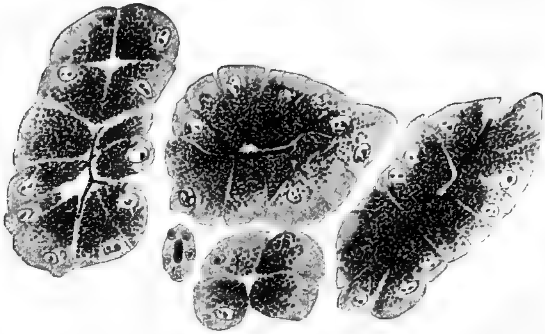

FIG. 512.—ALVEOLI OF DOG'S PANCREAS, CELLS LOADED: OSMIC PREPARATION. (Babkin, Rubasckin, and Ssawitsch.)

In the centre of each acinus there may generally be seen a few spindle-shaped cells (*centro-acinar cells* of Langerhans—fig. 508, *d*), the nature of which has not been definitely determined; but they appear to be continued from the cells which line the smallest ducts (fig. 508, *e*). Sometimes they are more conspicuous, and fill the parts of the alveoli which are nearest to the duct; in these cases the mass of cells which they form is liable to be mistaken for a Langerhans' islet. Diverticula from the lumen of the alveolus penetrate between the alveolar cells (fig. 514) as in serous glands generally.

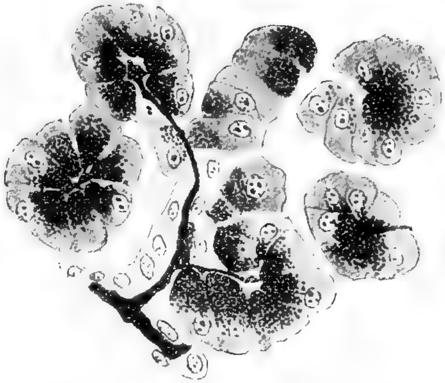

FIG. 513.—ALVEOLI OF DOG'S PANCREAS AFTER A PERIOD OF ACTIVITY PRODUCED BY APPLICATION OF ACID TO MUCOUS MEMBRANE OF DUODENUM. (Babkin, Rubasckin, and Ssawitsch.)

The pancreas has many nerves, with numerous small nerve-cells distributed upon their course; the nerve-fibrils end by ramifying amongst the cells of the alveoli, as in the salivary glands. In the cat, which has Pacinian bodies in its mesentery, these terminal organs are also found numerously in the substance of the pancreas, but this is a mere accident, resulting from the fact that the pancreas in the cat—as in many other animals—has a thin extension between the layers of the mesentery, and the last-named membrane always in the cat contains Pacinian corpuscles.

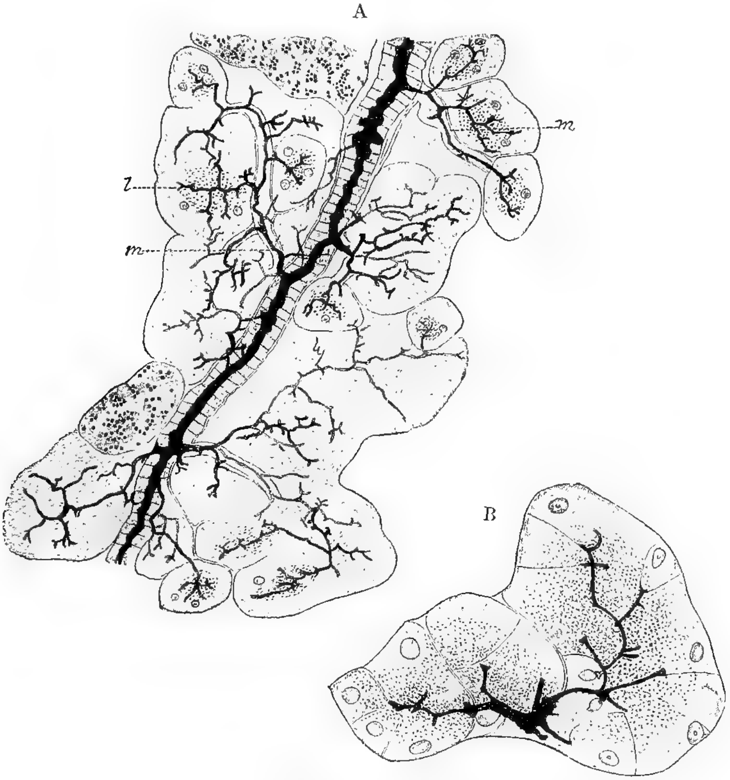

FIG. 514.—A DUCT OF THE PANCREAS WITH LATERAL DIVERTICULA INTO THE ALVEOLI: GOLGI METHOD. (E. Müller.)

In *A* the duct is shown cut longitudinally and giving off ductules, *m*, to the alveoli, where they extend between the cells, *l*. In *B* the details of their termination are shown more highly magnified.

Development.—The pancreas is formed from an outgrowth (at first solid, afterwards becoming hollowed out) of the entoderm of the small intestine much in the same way that the salivary glands are developed from the ectoderm of the mouth. The islets of Langerhans make their appearance as buds from the developing ducts, but they remain solid and do not acquire a lumen like the alveoli; their connexion with the ducts becomes lost and they become isolated in the midst of the glandular substance of the organs.

LESSON XXXVI.

THE KIDNEY, URETER AND BLADDER.

1. SECTIONS passing through the whole kidney of a small mammal, such as a mouse or rat. The sections will show the general arrangement of the organ and the disposition of the tubules and of the Malpighian corpuscles.

2. Thin sections of the kidney of a larger mammal, such as the dog or cat, may next be studied. In some the direction of the section should be parallel with the rays of the medulla; in others across their direction. The characters of the epithelium of the several parts of the uriniferous tubules and the structure of the glomeruli are to be made out in these sections.

3. Separate portions of the uriniferous tubules may be studied in teased preparations from a kidney which has been macerated in strong hydrochloric acid for a few hours. This renders it possible to unravel the tubules for some distance.

4. Thick sections of a kidney in which the blood-vessels have been injected. Examine these with a low power of the microscope. Follow the course of the arteries of the cortex sending their branches to the glomeruli, and observe the pencils of capillaries which run between the straight uriniferous tubules of the boundary zone. Notice the efferent vessels from the glomeruli breaking up into the network of capillaries distributed to the tubules.

5. Section across the lower part of the ureter. Another section may be taken across the upper part near the pelvis of the kidney.

6. Section of the urinary bladder vertical to the surface.

In the sections of the ureter and of the urinary bladder, notice the transitional epithelium resting on a mucous membrane, which is composed of areolar tissue without glands (in most animals); also the muscular coat outside the mucous membrane. In the ureter there is a layer of connective tissue outside the muscular coat, and at the upper part of the bladder a layer of serous membrane covering the muscular tissue.

The **kidney** is a compound tubular gland. To the naked eye it appears formed of two portions—a *cortical* and a *medullary* (fig. 515). The latter is subdivided in man into about twelve conical portions (*pyramids of Malpighi*), the base (boundary zone) of each being surrounded by cortical substance, while the apex projects in the form of a *papilla* into the dilated commencement of the ureter (*pelvis of the kidney*).[1] Both cortex and medulla are composed entirely of tubules—the *uriniferous tubules*—which have a straight direction in the medulla and a contorted arrangement in the cortex; but groups of straight tubules also pass from the medulla through the thickness of the cortex as the so-called *medullary rays* (figs. 515, 516).

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[1] In many animals (*e.g.* dog, cat, rabbit, monkey) the whole kidney is formed of only a single pyramid; in others the pyramids are even more numerous than in man.

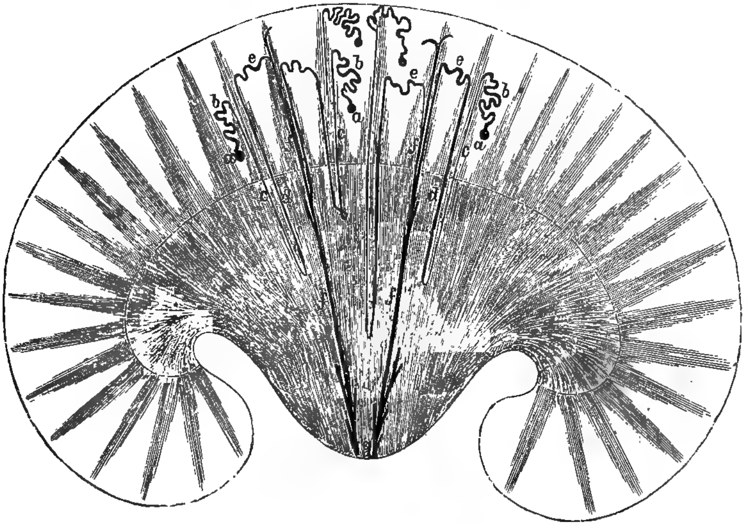


FIG. 515.—DIAGRAM OF THE COURSE OF THE TUBULES IN A UNIPYRAMIDAL KIDNEY, SUCH AS THAT OF THE RABBIT. (Toldt.)

a, Malpighian bodies; *b*, first convoluted tubule; *c*, *d*, looped tube of Henle; *e*, second convoluted; *f*, collecting tube; *g*, ducts of Bellini.

The **uriniferous tubules** begin in the cortical part of the organ in dilatations, each enclosing a tuft or glomerulus of convoluted capillary blood-vessels (*corpuscles of Malpighi*), the dilated commencement of the tubule being known as the *capsule* (fig. 519, M). The *glomerulus* is lobulated (figs. 517, 518); the lobules being united by the branches of the afferent and efferent vessels; it is covered by a flattened epithelium reflected from that lining the capsule; this epithelium dips in between the lobules. The glomeruli near the medulla are larger than the rest and have more lobules. The capillary-wall in all the glomeruli is a syncytium, showing no cell-outlines in silver preparations (Drasch).

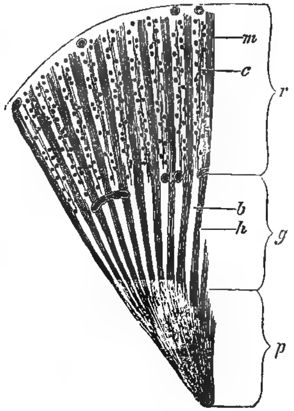


FIG. 516.—SECTION THROUGH PART OF A DOG'S KIDNEY. (Ludwig.)

p, papillary, and *g*, boundary zones of the medulla; *r*, cortical layer; *h*, bundles of tubules in the boundary layer, separated by spaces, *b*, containing bunches of vessels (not here represented), and prolonged into the cortex as the medullary rays, *m*; *c*, intervals of cortex, composed chiefly of convoluted tubules, with irregular rows of glomeruli, between the medullary rays.

The *tubule* leaves the capsule by a *neck* (fig. 519, *n*) which is, however, rarely narrower than the rest of the tubule in mammals. In some

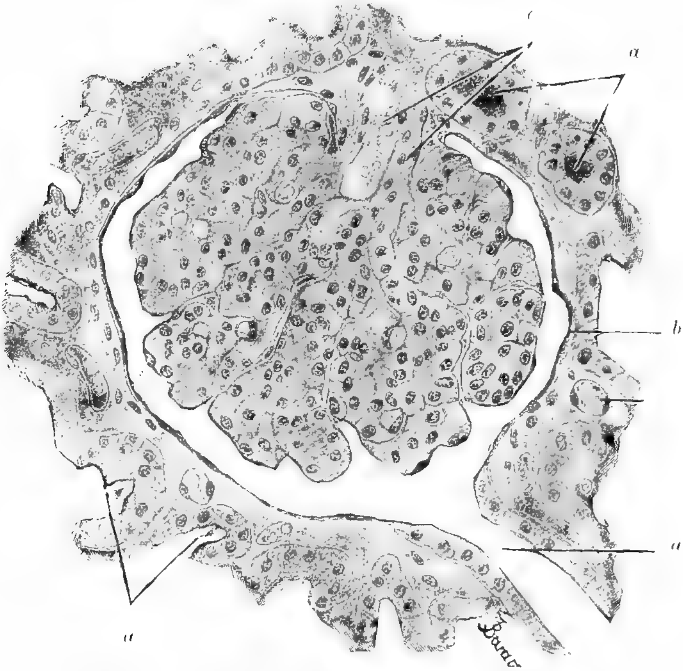


FIG. 517.—A MALPIGHIAN CORPUSCLE FROM THE KIDNEY OF THE MONKEY. (Szymonowicz.) Magnified 350 diameters.

a, *a*, sections of convoluted tubules; *a'*, commencement of convoluted tube from capsule; *b*, capsule; *c*, afferent and efferent vessels of glomerulus.

animals (*e.g.* frog) the neck is long, and has ciliated epithelium. The tubule is at first convoluted (*first or distal convoluted tubule*). It then becomes nearly straight or slightly spiral only (*spiral tubule*), and rapidly narrowing passes down into the medulla towards the dilated commencement of the ureter as the *descending limb of the looped tubule of Henle.* It does not at once, however, open directly into the pelvis of the kidney, but before reaching the end of the papilla it turns round in the form of a loop (*loop of Henle*), and passes upwards again towards the cortex, parallel to its former course, and larger than before (*ascending limb of looped tubule of Henle*). Arrived at the

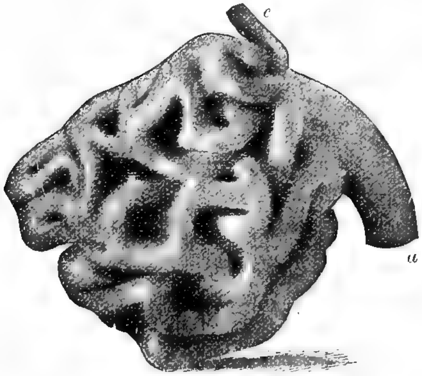


FIG. 518. MODEL OF A GLOMERULUS. (Johnston.)

a, afferent; *e*, efferent blood-vessel.

cortex it approaches close to the capsule from which the tubule took origin, but at a point opposite to the origin, viz., near the afferent and efferent vessels of the glomerulus (Golgi). It then becomes larger and irregularly zigzag (*zigzag or irregular tubule*), and again somewhat convoluted (*second or proximal convoluted tubule*). Eventually it straightens out again and narrowing into a small vessel (*junctional tubule*), joins a *straight or collecting tubule.* The last-named unites with others to form larger collecting

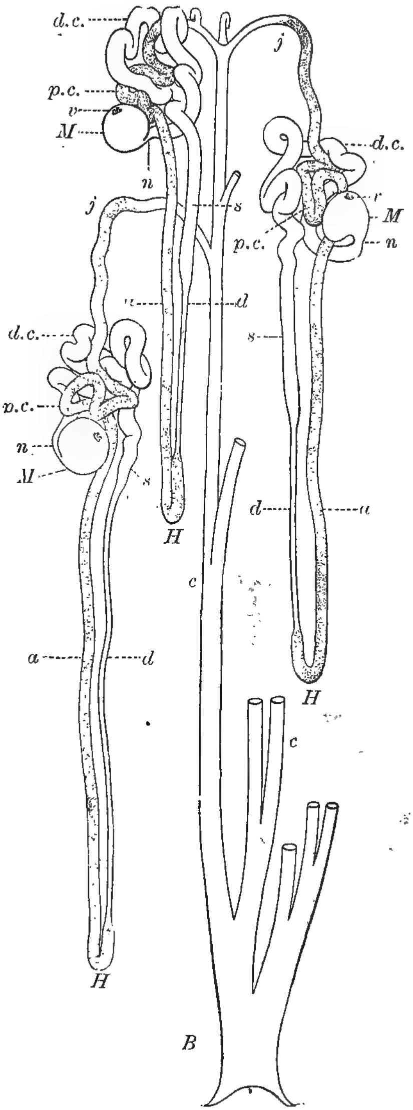


FIG. 519.—PLAN OF THE ARRANGEMENT OF THE URINIFEROUS TUBULES. (Huber.)

M, Malpighian corpuscles; *v*, point of entrance of vessels of glomerulus; *n*, neck; *d.c.*, distal convoluted tubule, which arises from the Malpighian corpuscle; *s*, spiral tubule into which it is continued; *d*, narrow descending limb of loop of Henle; *H*, loop of Henle (this is sometimes formed by the narrow part of the looped tubule, but is here represented as formed by the wider part); *a*, wider ascending limb of loop of Henle; this passes back to the neighbourhood of the same Malpighian corpuscle, often becoming irregular and zigzag at its upper end. Here it becomes continuous with the proximal convoluted tubule, *p.c.*, which eventually passes into the junctional tubule, *j*, by which it is connected with a collecting tubule, *c*. *B*, duct of Bellini, receiving a number of conjoined collecting tubules and opening at a papilla.

tubes which pass through the medullary substance of the kidney to open at the papilla as the *ducts of Bellini* (fig. 520).

The tubules are throughout bounded by a basement-membrane, which is lined by epithelium; the characters of the epithelium-cells vary in the different parts of a tubule. In the *capsule* (fig. 517), the epithelium is flattened and is reflected over the glomerulus. In some animals (*e.g.* mouse) the granular epithelium of the convoluted tube is prolonged a little way into the capsule. In the first *convoluted* and *spiral tubules* the epithelium is thick, and the cells are markedly granular, with a tendency for the basal granules (mitochondria) to be arranged in longitudinal rows as in the

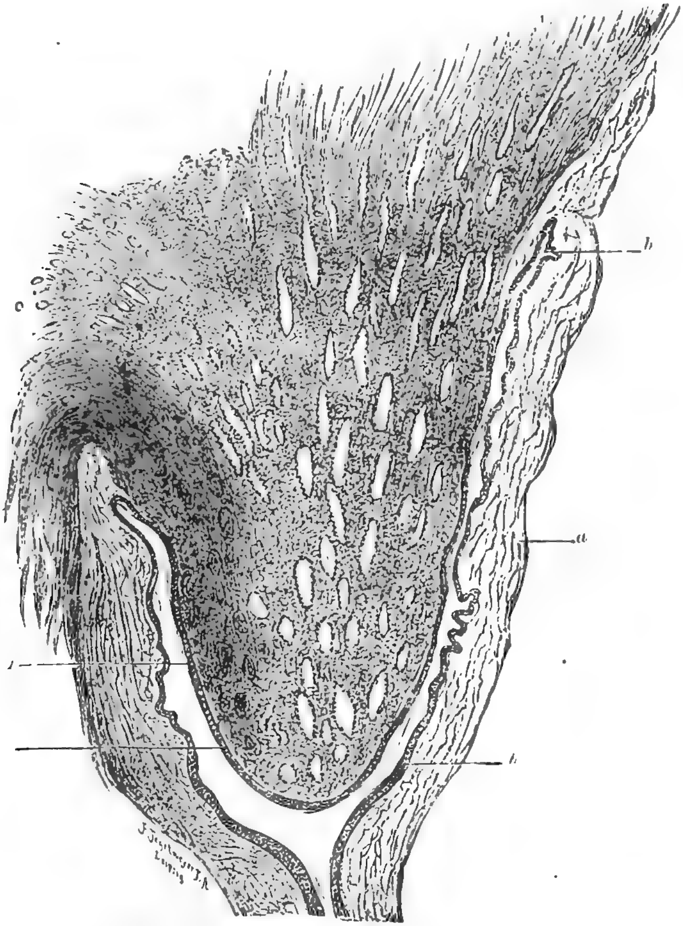


FIG. 520.—LONGITUDINAL SECTION THROUGH A PAPILLA OF THE KIDNEY, SHOWING ITS PROJECTION AT ONE OF THE CALICES OF THE KIDNEY-PELVIS. (Disse.)

The ducts of Bellini are seen cut obliquely; the smaller tubules are looped tubules of Henle; *a*, epithelium covering papilla; *b*, epithelium lining calix; *c*, cavity of calix; *d*, connective tissue.

cells of the salivary ducts (rodded or fibrillar appearance, fig. 522). The granules near the lumen are not so arranged and are eosinophil. The cells often exhibit a brush of cilium-like processes projecting into the lumen (fig. 522), but these are not vibratile. In the narrow *descending limb of the looped tubules*, and in the loop itself, the cells are clear and flattened (fig. 523), and leave a relatively large lumen; in the *ascending limb* they again acquire a granular or fibrillar structure and may nearly fill the lumen. The arrangement of the cell-granules in lines perpendicular to the basement-membrane is still more marked in the *zigzag tubules*, and a similar structure is present also in the *second convoluted tubules*, into which these pass. On the other hand, the *junctional tubule* has a larger lumen and in it the granular striated epithelium gives place to clear

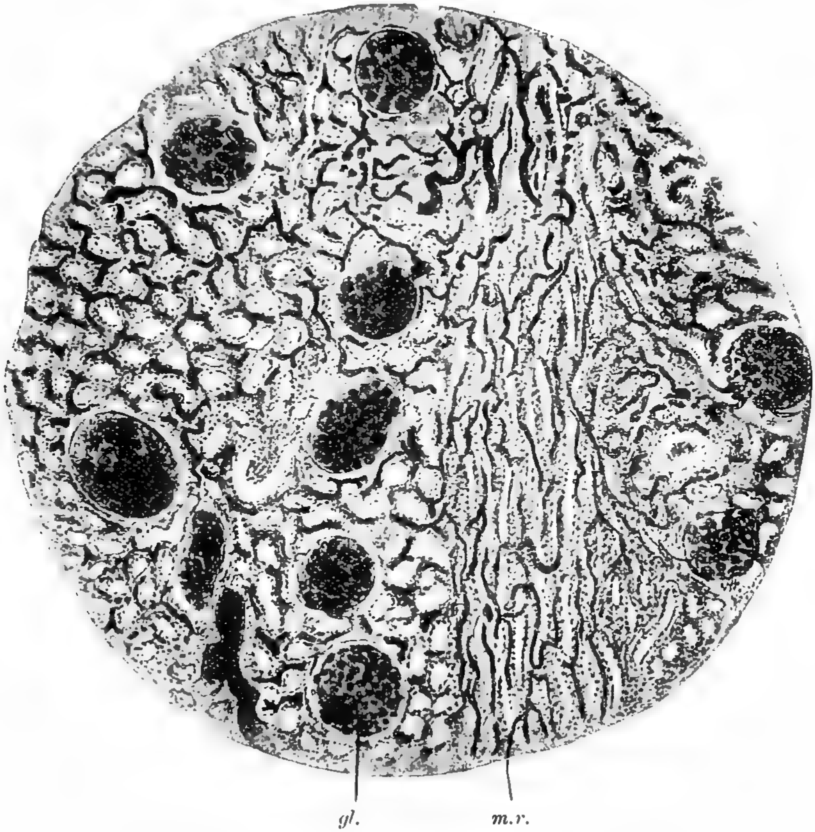


FIG. 521.—PART OF A SECTION THROUGH THE CORTEX OF A HUMAN KIDNEY, THE BLOOD-VESSELS OF WHICH HAVE BEEN INJECTED. (Disse.)

gl., a glomerulus; *m.r.*, section of a medullary ray.

flattened cells. The *collecting tubes* have also a very distinct lumen and are lined by clear cubical or columnar epithelium-cells (fig. 527, *a*).

The following gives a tabular view of the parts which compose a uriniferous tubule, and the nature of the epithelium in each part :—

PORTION OF TUBULE.	NATURE OF EPITHELIUM.	POSITION OF TUBULE.
Capsule . .	Flattened, reflected over glomerulus, where its cells are said to form a syncytium	Labyrinth of cortex.[1]
Distal convoluted tubule	Cubical, granular, with appearance of fibrillation ("rodded"), the cells interlocking	Labyrinth of cortex.
Spiral tubule .	Like the last . .	Medullary ray of cortex.
Descending limb of looped tubule	Clear flattened cells	Boundary zone and partly papillary zone of medulla.
Loop of Henle .	Like the last (or may be like the ascending limb)	Papillary zone of medulla.
Ascending limb of looped tubule	Cubical, granular; the cells sometimes imbricated	Medulla, and medullary ray of cortex.
Zigzag tubule .	Cells strongly "rodded"; varying height, lumen small	Labyrinth of cortex.
Proximal convoluted tubule	Similar to distal convoluted tube, but cells are longer, with larger nuclei, and they have a more refractive aspect	Labyrinth of cortex.
Junctional tubule .	Clear flattened and cubical cells .	Labyrinth, passing to medullary ray.
Straight or collecting tubule	Clear cubical and columnar cells .	Medullary ray and medulla.
Duct of Bellini .	Clear columnar cells . .	Opens at apex of papilla.

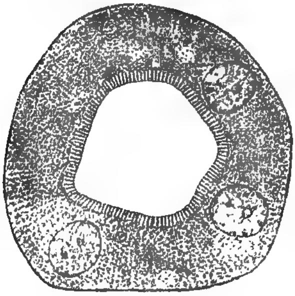


FIG. 522.—SECTION OF A CONVOLUTED TUBULE OF THE RABBIT'S KIDNEY, SHOWING THE STRUCTURE OF THE EPITHELIUM. (Szymonowicz.) Magnified 1100 diameters.

Blood-vessels.—The renal artery divides into branches on entering the organ, and these branches pass towards the cortex, forming arched vessels between the cortex and the medulla (fig. 524, *a*). The branches of the renal vein which are similarly placed are more distinctly arched (*g*). From the arterial arches vessels pass through the cortex (*cortical or interlobular arteries, b*), and give off at intervals (in some animals from one side only) small arterioles (*afferent vessels of the glomeruli*), each of which enters the dilated commencement of a uriniferous tubule, within which its capillaries form a glomerulus. From the glomerulus a somewhat smaller *efferent vessel* passes out, and this at once again breaks up into capillaries, which are distributed amongst the tubules of the cortex (*e*). Their blood is collected by veins which run parallel with the cortical arteries but not in juxtaposition with them. These veins join the venous arches between the cortex and the medulla. They receive blood from certain other veins which arise by radicles having a somewhat stellate arrangement near the capsule (*venæ stellulæ, j*).

---

[1] The part of the cortex between and surrounding the medullary rays is so named.

The medulla derives its blood-supply both from special offsets of the arterial arches, which immediately break up into pencils of fine straight arterioles running in groups between the straight tubules of the medulla, and from the efferent vessels of the glomeruli which are near the medulla. These vessels supply a capillary network with elongated meshes which pervades the medulla (fig. 524, *f*), and which terminates in a plexus of somewhat larger venous capillaries in the papilla. From these capillaries the venules of the medulla collect the blood, and pass, accompanying the straight arterioles, into the venous arches between the cortex and medulla. The groups of small arteries and veins (*vasa recta*) in the part of the medulla nearest to the cortex alternate with groups of the uriniferous tubules; this arrangement confers a striated aspect upon that part of the medulla (*boundary zone*, fig. 516, *g*).

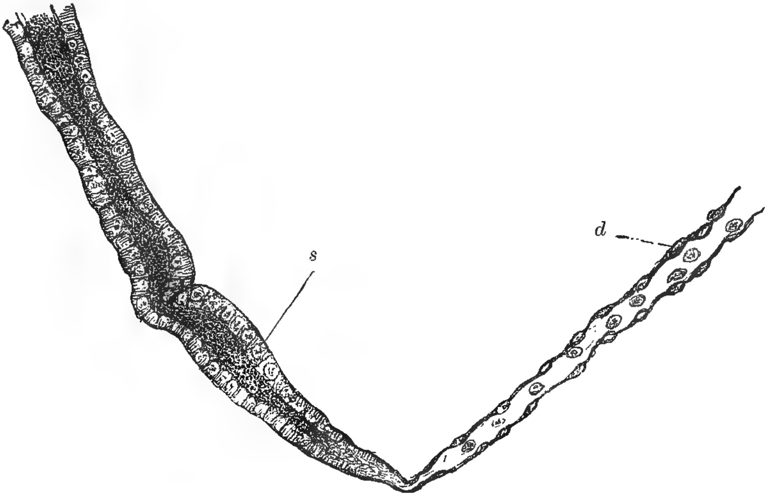


FIG. 523.—PASSAGE OF THE SPIRAL CONTINUATION OF A DISTAL CONVOLUTED TUBULE INTO THE DESCENDING LIMB OF LOOPED TUBULE OF HENLE. (Disse.) The bend is accidental.

s, end of spiral tubule; *d*, narrow descending limb of looped tubule of Henle.

In some animals most of the blood-supply of the medullary tubules comes from the efferent vessels of the deep glomeruli.

Between the uriniferous tubules, and supporting the blood-vessels, is a variable amount of connective tissue, greatest in quantity in the papillæ (fig. 527), containing cleft-like lymphatics.

Nerve-fibrils ramify amongst the epithelium-cells of the tubules (fig. 528), but most of the nerves to the kidneys are distributed to the blood-vessels.

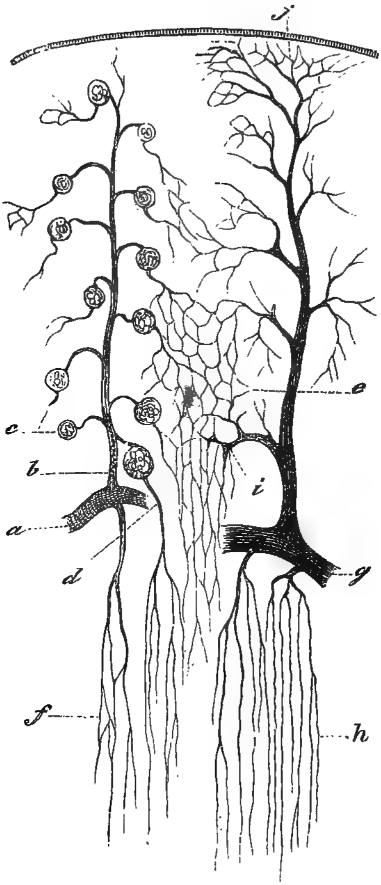


FIG. 524.—VASCULAR SUPPLY OF KIDNEY. (Cadiat.)

a, part of arterial arch; *b*, interlobular artery; *c*, glomerulus; *d*, efferent vessel passing to medulla; *e*, capillaries of cortex; *f*, capillaries of medulla; *g*, venous arch; *h*, straight veins of medulla; *j*, vena stellula; *i*, interlobular vein.

Development of the uriniferous tubules.—The ducts of Bellini and the collecting tubules are derived as hollow sprouts from the enlarged upper end of the ureter, which in its turn is formed as a bud from the Wolffian duct of the embryo. The rest of the uriniferous tubule, including the Malpighian corpuscle, is formed from a hollow S-shaped island of cells which become differentiated in the mesoderm near the blind end of a collecting tubule. The lower part of the S forms a spoon-shaped structure, within the bowl of which the vessels of the glomeruli are developed; the sides of the bowl then grow round and completely

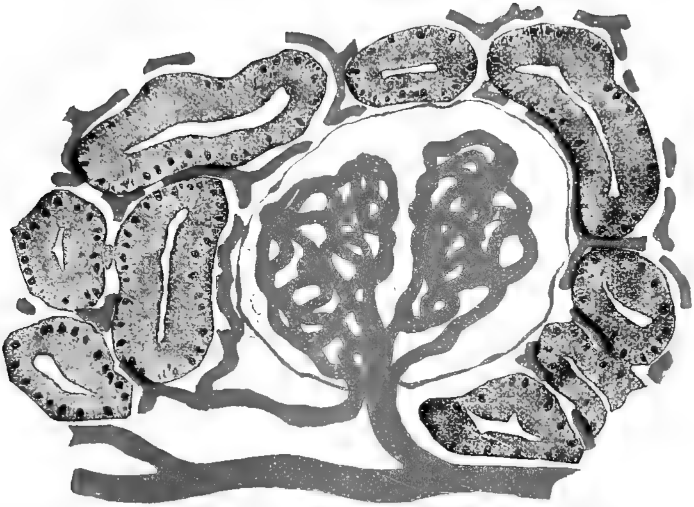


Fig. 525.—From an injected kidney. (Prenant and Bouin.)

Cortical arteriole on the left giving off an afferent vessel to the glomerulus. From this a (smaller) efferent vessel comes off and joins the capillaries surrounding the tubules.

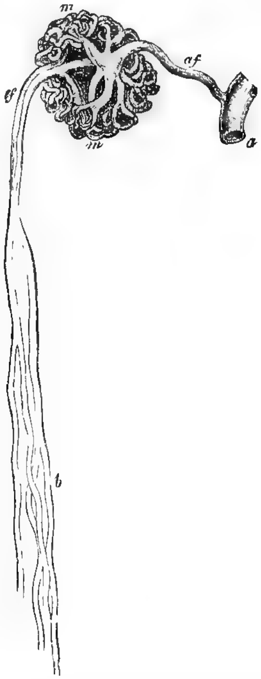


Fig. 526.—A glomerulus from the part of the cortex of the horse's kidney nearest the medulla: injected. (Bowman.) Magnified 70 diameters.

a, cortical artery; *af*, afferent vessel of glomerulus; *mm*, glomerulus; *ef*, efferent vessel breaking up into a pencil of capillaries, *b*, which pass down between the tubules of the medulla.

enclose them. The upper part of the S forms a convoluted tubule which before long makes connexion with the previously blind end of the forked collecting tubule. At first there is no sign of the looped tubule, but this presently grows down from the convoluted tubule, very much as if a part of this tube had been drawn out towards the papilla. The several stages of formation of the uriniferous tubule are shown in the diagrams marked 1 to 5 in fig. 529. These diagrams exhibit nine stages of development of the tubules, since in every one, except diagram 3, an earlier stage is represented upon the left-hand side, and a later upon the right-hand side.

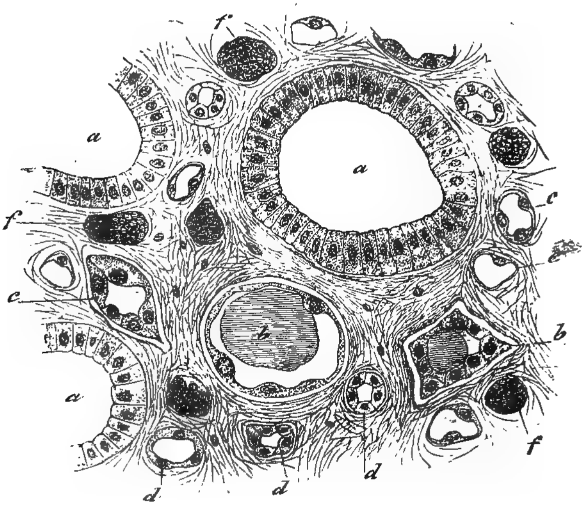


FIG. 527.—SECTION ACROSS A PAPILLA OF THE KIDNEY. (Cadiat.)
a, large collecting tubes (ducts of Bellini); *b*, *c*, *d*, tubules of Henle; *e*, *f*, blood-capillaries.

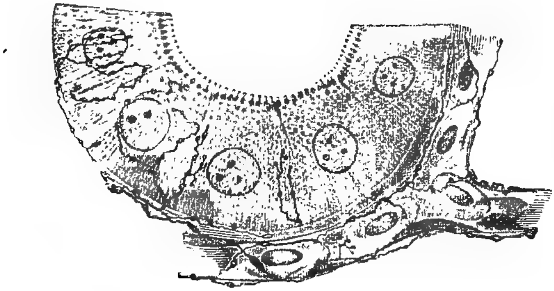


FIG. 528.—NERVE-FIBRILS ENDING OVER CAPILLARY BLOOD-VESSELS AND AMONGST THE EPITHELIUM-CELLS OF A CONVOLUTED TUBE OF THE FROG'S KIDNEY. (Smirnow.)

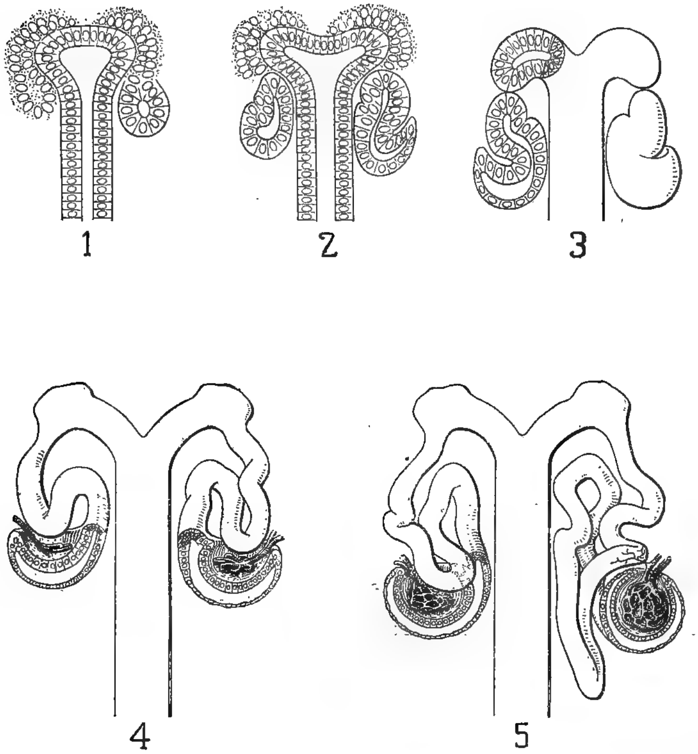


FIG. 529.—FIVE DIAGRAMS TO ILLUSTRATE THE MODE OF DEVELOPMENT OF THE URINIFEROUS TUBULES AND THE GLOMERULI. (Huber.)

THE URETER AND BLADDER.

The **ureter** (fig. 530) is a muscular tube lined by mucous membrane. The *muscular coat* consists of two layers of plain muscular tissue, an outer circular, and an inner longitudinal. In the lower part there are some longitudinal bundles external to the circular. Outside the muscular coat is a layer of connective tissue in which the blood-vessels and nerves ramify before entering the muscular layer.

The *mucous membrane* is composed of areolar tissue, and is lined by transitional epithelium, like that of the bladder.

The **urinary bladder** has a muscular wall lined by a strong mucous membrane and covered in part by a serous coat.

The *muscular coat* consists of three layers, but the innermost is incomplete. The principal fibres run longitudinally and circularly; the circular fibres are collected into a layer of some thickness which immediately surrounds the commencement of the urethra. The *mucous membrane* is lined by a transitional stratified epithelium (fig. 531). The shape and structure of the cells have already been studied (p. 66). Many of the superficial cells have two nuclei. Gland-like invaginations of the epithelium are occasionally found near the base of the bladder in man (fig. 531); in the bladder of some animals well-marked glands constantly occur.

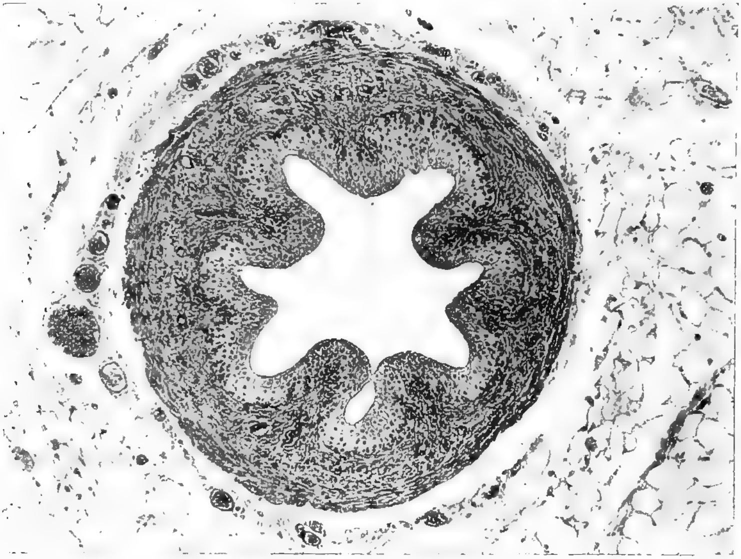


FIG. 530.—SECTION ACROSS URETER: DOG. Magnified 90 diameters.

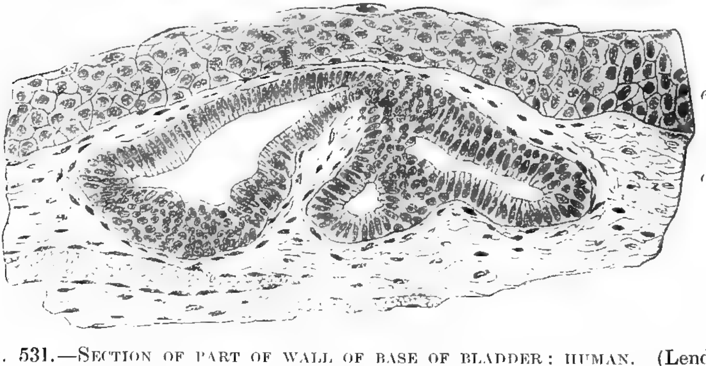


FIG. 531.—SECTION OF PART OF WALL OF BASE OF BLADDER: HUMAN. (Lendorf.) Magnified 230 diameters.

The section passes through a glandular invagination of the epithelium. *ep*, epithelium; *c*, corium.

The *nerves* to the bladder form gangliated plexuses, and are distributed to the muscular tissue and blood-vessels: some are said to enter the epithelium.

LESSON XXXVII.

THE MALE GENERATIVE ORGANS.

1. Sections across the penis (child or monkey). The blood-vessels of the organ should be injected with the hardening fluid so as the better to exhibit the arrangement of the venous spaces which constitute the erectile tissue. Notice the large venous sinuses of the corpora cavernosa and the smaller spaces of the corpus spongiosum ; in the middle of the latter is seen the (flattened) tube of the urethra.

2. Section of prostate gland (child or monkey). Notice the glandular tubes and the plain muscular tissue of the prostate. The character of the urethral epithelium may also be observed.

3. Section of testicle and epididymis. The sections may be made from a testicle (rat or cat) which has been hardened in alcohol or formol ; they can be stained with hæmatoxylin and eosin or with iron-hæmatoxylin. In these sections notice the strong capsule surrounding the gland, the substance of which consists of tubules which are variously cut ; and the epithelium of the tubules, which is in different phases of development in different tubules. Observe the strands of polyhedral interstitial cells, much more numerous in some animals, lying in the loose tissue between the tubules ; also the lymphatic clefts in that tissue. Notice in sections through the epididymis the lining epithelium and the spermatozoa within the lumen of the tube.

Sketch carefully under a high power the contents of some of the seminiferous tubules to illustrate the mode of formation of spermatozoa.

4. Section of vesicula seminalis, fixed and hardened in formol and stained with hæmatoxylin and eosin or with iron-hæmatoxylin. Notice the two-layered epithelium, the more superficial cells being long and columnar but not ciliated ; the deeper cells short and swollen out by clear fluid.

5. Examination of spermatozoa. Spermatozoa may be obtained fresh from the testicle or epididymis of a recently killed mammal and examined in saline solution. Their movements may be studied on the warm stage ; to display their structure a very high power of the microscope is necessary. They may be preserved and stained as "film" preparations, as with marrow (p. 32).

THE PENIS, URETHRA AND PROSTATE.

The **penis** is for the most part composed of cavernous tissue which is collected into three principal masses—the *corpora cavernosa*, one on each side, and the *corpus spongiosum* in the middle line inferiorly. The corpus spongiosum becomes enlarged near its termination to form the glans. It is traversed throughout by the urethra, which extends from the bladder to the apex of the glans. Each of these masses is bounded by a strong capsule of fibrous and plain muscular tissue, containing many elastic fibres and sending in strong septa or trabeculæ of the same tissues, which form the boundaries of the cavernous spaces of the erectile tissue (fig. 533). The arteries of the tissue run in the trabeculæ, and their capillaries open into the cavernous spaces. On the other hand, the spaces are connected with efferent veins. The arteries of the cavernous tissue may sometimes in injected specimens be observed to form looped or twisted projections into the cavernous spaces (*helicine arteries of Müller*), into which they then open directly. The arteries of the cavernous tissue often have localised thicknesses of the inner coat, and many of the veins have longitudinal muscle-fibres in the inner coat which form pad-like projections into the lumen.

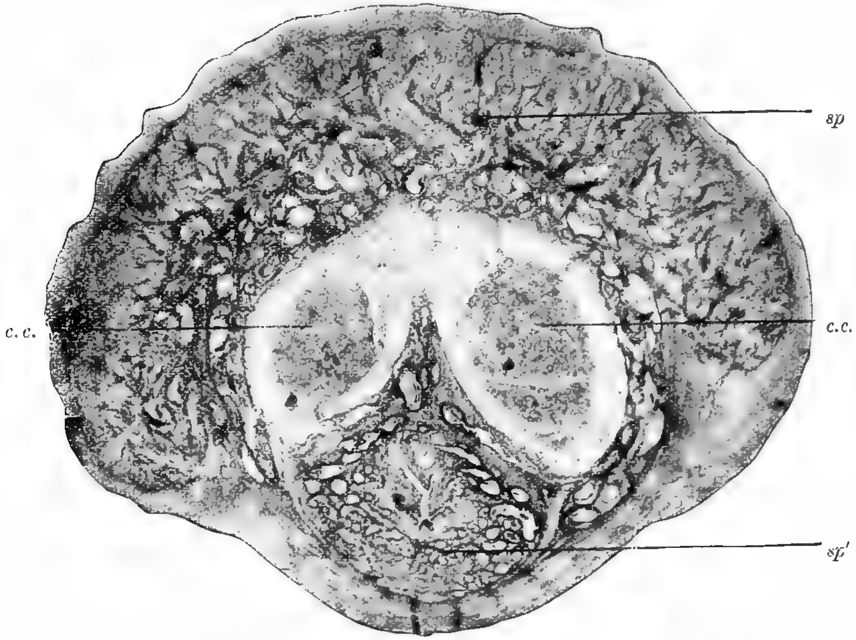


FIG. 532.—TRANSVERSE SECTION OF GLANS PENIS OF CHILD. (Rothfeld.)

c.c., corpora cavernosa; *sp*, corpus spongiosum; *sp'*, corpus spongiosum urethræ, with the lumen of the urethra in the centre appearing as an irregular slit with folded walls.

The integument, especially that of the glans, contains numerous special nerve-end organs of the nature of end-bulbs. Pacinian bodies are also found upon the deeper nerves. Lymphatic vessels are numerous in the integument of the organ and in the submucous tissue of the urethra.

Urethra.—The lumen of the urethra appears in sections across the penis in the form of an irregular cleft in the middle of the corpus spongiosum (fig. 532). It is lined in the prostatic part by transitional, but elsewhere by columnar epithelium, except near its orifice, where the epithelium is stratified. The urethral epithelium rests upon a very vascular mucous membrane. Outside this is a coat of submucous tissue, with two layers of plain muscular fibre—an inner longitudinal and an outer circular. Some of the fibres are cross-striated. Outside the muscular coat is a close plexus of small veins which is connected with, and may be said to form part of, the corpus spongiosum.

The *mucous membrane* of the urethra is beset with small mucous glands, simple and compound (*glands of Littré*). There are also a number of oblique recesses termed *lacunæ*. Besides these small glands and glandular recesses, two compound racemose glands open into the bulbous portion of the urethra in the male (*Cowper's glands*). Their acini are lined by clear columnar cells which yield a mucus-like secretion and appear to be of similar nature to those of the glands of Littré (fig. 534).

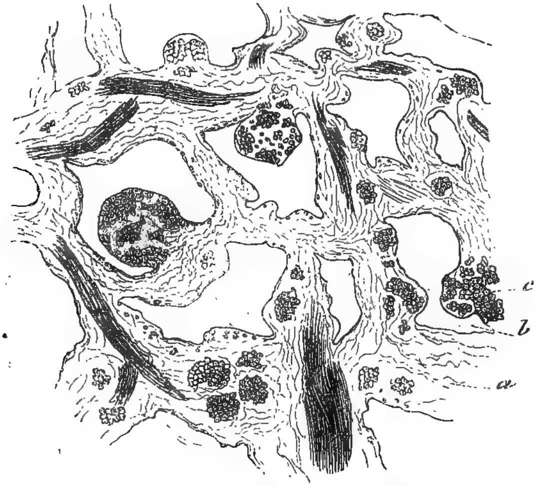


FIG. 533.—SECTION OF ERECTILE TISSUE. (Cadiat.)

a, trabeculæ of connective tissue, with elastic fibres, and bundles of plain muscular tissue, some cut across (*c*); *b*, blood-sinuses.

The **prostate**, which surrounds the commencement of the urethra in the male, is a muscular and glandular mass, the glands of which are composed of tubular alveoli, lined by columnar epithelium, with smaller cells lying between them and the basement-membrane (fig. 535). Their ducts open upon the floor of the urethra. In older subjects the tubules often contain colloid or calcareous concretions. The muscular tissue is of the plain variety.

The prostate is pierced by the two common ejaculatory ducts which open one on each side of a median elevation of the mucous membrane of the floor of the urethra. Between these orifices is an aperture leading into the prostatic utricle (*uterus masculinus*). The blood-vessels and nerves of the prostate are numerous. The nerves are provided with small ganglia and are distributed partly to the muscular tissue, partly to the glands; others which are sensory pass to the capsule, and to the wall of the urethra. The sensory nerves end in plexuses and in peculiar terminal corpuscles like simple Pacinian bodies.

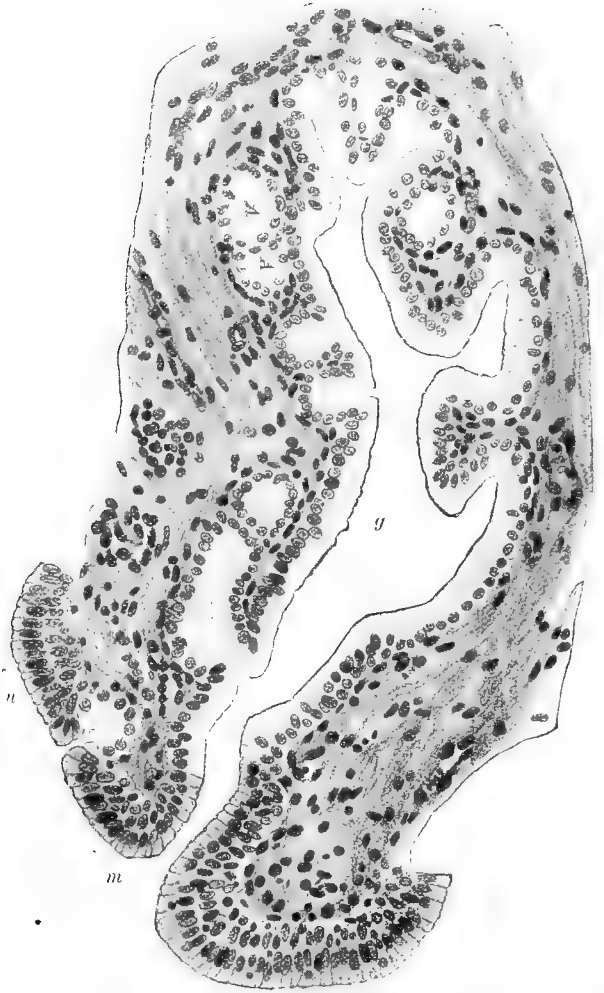


FIG. 534.—SECTION THROUGH THE OPENING OF THE DUCT OF A GLAND INTO THE MALE URETHRA. (Lichtenberg.)

g, gland; *m*, its mouth; *u*, epithelium of urethra. The gland is similar in structure to Cowper's glands, but simpler in conformation. Its cells are mucus-secreting.

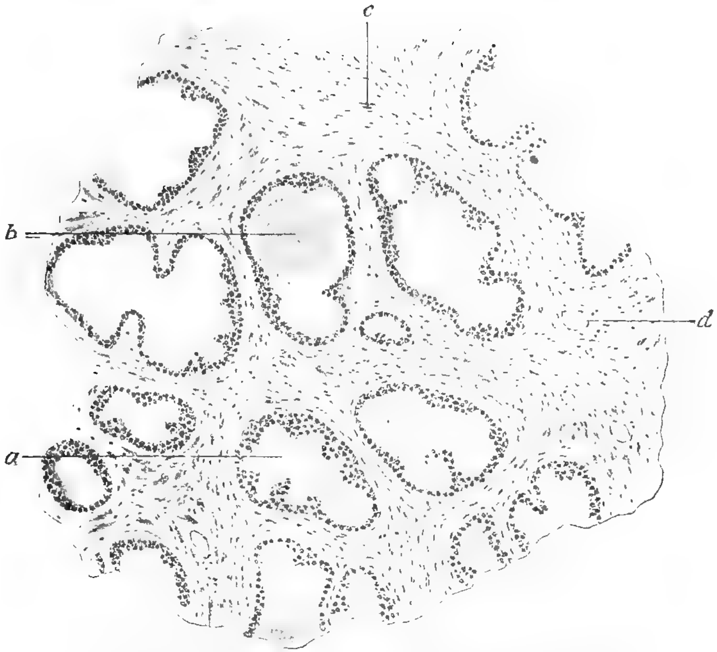


FIG. 535. SECTION OF PROSTATE OF MONKEY. (Marshall.)
a, alveolus; *b*, a concretion within an alveolus; *c*, stroma; *d*, a blood-vessel.

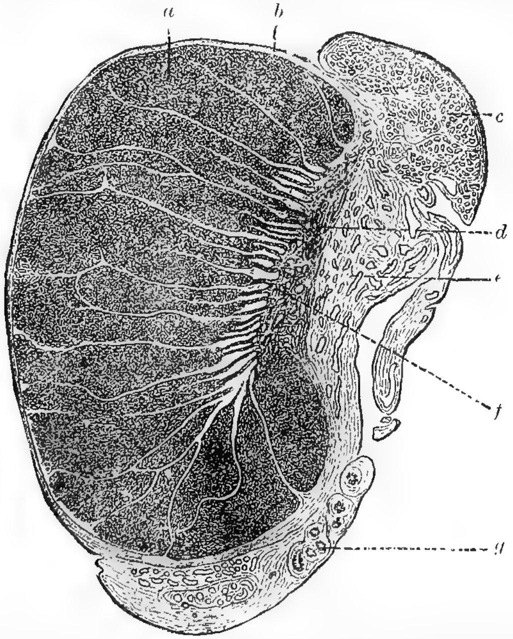


FIG. 536.—SECTION OF HUMAN TESTIS AND EPIDIDYMIS. (Böhm and v. Davidoff.)
a, glandular substance divided into lobules by septa of connective tissue; *b*, tunica albuginea; *c*, head of epididymis; *d*, rete testis; *e*, middle part or body of epididymis; *f*, mediastinum giving origin to the septa; *g*, sections of the commencing vas deferens.

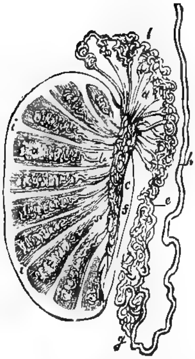


FIG. 537.

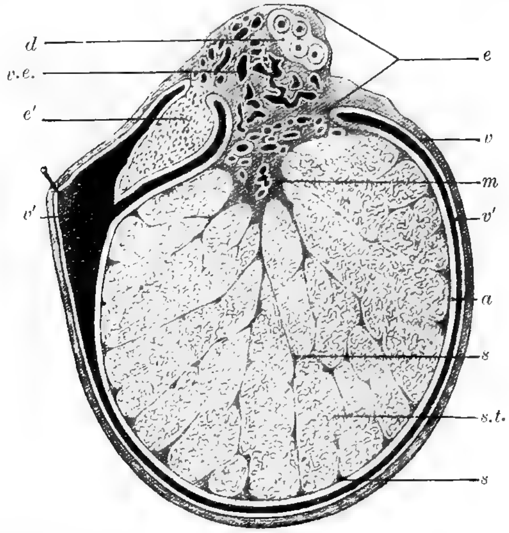


FIG. 538.

FIG. 537.—PLAN OF ARRANGEMENT OF TUBULES AND DUCTS OF TESTICLE.

a, tubuli contorti; *b*, tubuli recti; *c*, rete testis; *d*, vasa efferentia; *e*, *f*, *g*, convoluted tube of the epididymis; *h*, vas deferens; *i*, tunica albuginea with trabeculæ.

FIG. 538.—TRANSVERSE SECTION OF TESTICLE AND EPIDIDYMIS: MAN. (Eberth.)

a, tunica albuginea; *s.t.*, seminiferous tubules; *s*, trabeculæ dividing the gland into lobules; *v*, tunica vaginalis; *v'*, cavity of tunica vaginalis; *m*, mediastinum testis; *e*, epididymis; *e'*, caput epididymis; *v*, vas deferens (cut four times); *v.e.*, vasa efferentia.

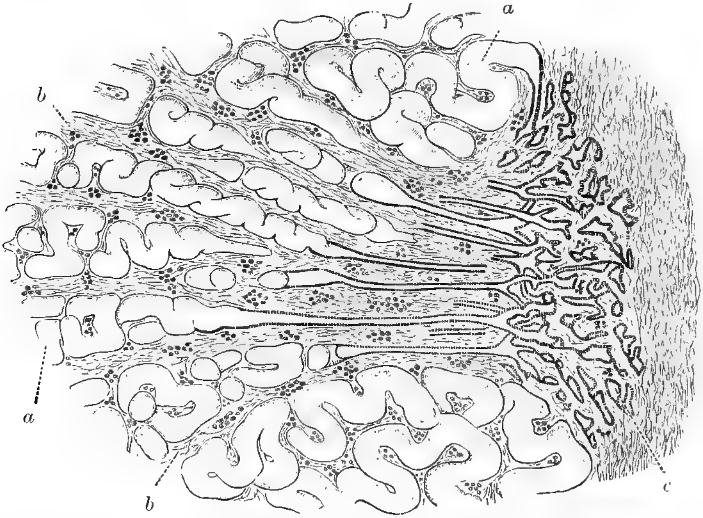


FIG. 539.—PASSAGE OF CONVOLUTED SEMINIFEROUS TUBULES INTO STRAIGHT TUBULES AND OF THESE INTO THE RETE TESTIS. (Mihalkowicz.)

a, *a*, seminiferous tubules; *b*, fibrous stroma continued from the mediastinum testis; *c*, rete testis.

THE TESTICLE AND ITS DUCTS.

The **testicle** is enclosed by a strong fibrous capsule, the *tunica albuginea* (figs. 536, 537, 538). This is covered externally with a layer of serous epithelium reflected from the *tunica vaginalis.* From its inner surface there proceed fibrous processes or *trabeculæ,* which imperfectly subdivide the organ into lobules, and posteriorly the capsule is prolonged into the interior of the gland in the form of a mass of fibrous tissue, which is known as the *mediastinum testis.* Attached to the posterior margin of the body of the gland is a mass (*epididymis*) which when investigated is found to consist of a single convoluted tube, receiving at its upper end the *efferent ducts* of the testicle and prolonged at its lower end into a thick-walled muscular tube, the *vas deferens,* which conducts the secretion to the urethra.

The glandular substance of the testicle is wholly made up of *convoluted tubules* (tubuli contorti), which when unravelled are of very considerable length. Each commences near the tunica albuginea, and after many windings terminates, usually after joining one or two others, in a *straight tubule.* The straight tubules (tubuli recti) pass into the mediastinum, and there form by their union a network of intercommunicating vessels of varying size, which is known as the *rete testis* (fig. 539). From the rete a limited number of efferent ducts or tubules (*vasa efferentia*) arise, and after a few convolutions pass into the tube of the epididymis.

The *straight tubules* which lead from the convoluted seminiferous tubes into the rete testis are lined only by a single layer of clear flattened or cubical epithelium. The tubules of the *rete* also have a simple epithelial lining; both in these and in the straight tubules the basement-membrane is absent, the epithelium being supported directly by the connective tissue of the mediastinum.

The *efferent tubules* which pass from the rete to the epididymis are lined by columnar ciliated epithelium. In man their lumen is irregular in section, and the inner surface pitted with glandular depressions lined by short clear non-ciliated cells.

Epididymis.—This is composed of a single convoluted tube 6 to 8 meters long which receives the vasa efferentia above, and below is continued into the vas deferens. The tube is lined by long columnar cells with oval nuclei, having at their bases smaller polyhedral cells with spherical nuclei (figs. 540, 541). The columnar cells are provided with bunches of cilia projecting into the lumen of the tube, but it is alleged that these cilia are not always vibratile. The cells exhibit canaliculi in their cytoplasm, which, according to Holmgren, communicate with the exterior at the attached border of the cell (fig. 542).

The **vas deferens** (fig. 543) is a thick-walled tube, formed of an outer layer of longitudinal bundles of plain muscular tissue, and an inner equally thick layer of circular bundles of the same tissue; within this again is a thinner layer of longitudinal muscle. There is a good deal of connective and elastic tissue between the muscular bundles. The tube is lined by a mucous membrane, the inner surface of which is covered by columnar non-ciliated epithelium.

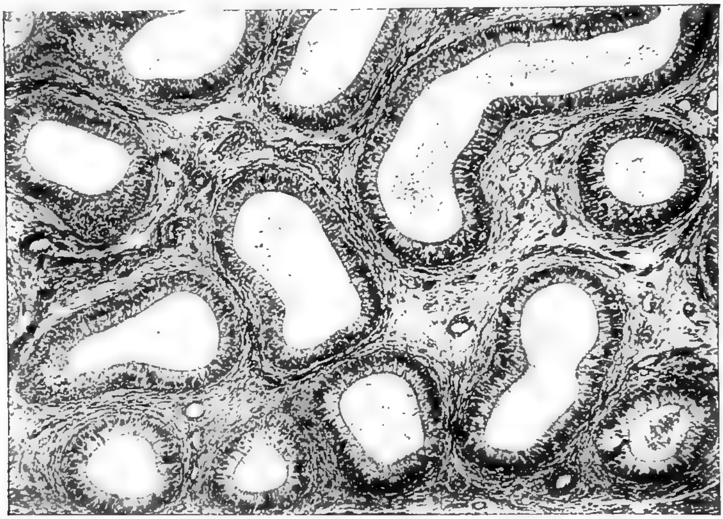


FIG. 540.—FROM A SECTION OF THE EPIDIDYMIS: HUMAN. Magnified 60 diameters. Photograph. From a preparation by Prof. M. Heidenhain.

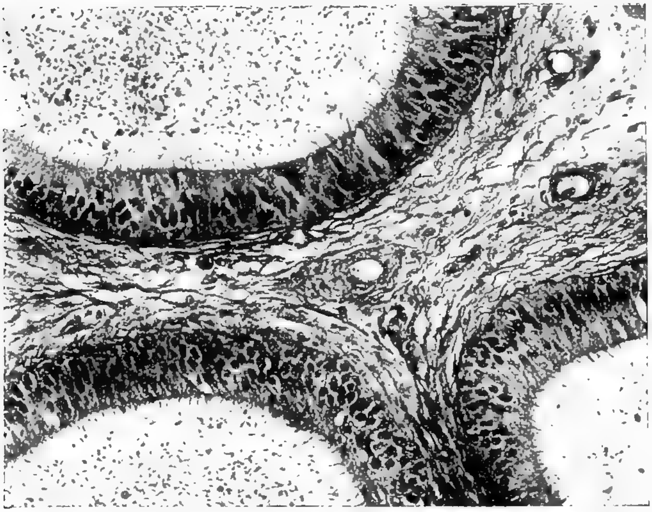


FIG. 541.—PART OF THE SECTION SHOWN IN THE ABOVE FIGURE. Magnified 200 diameters. The tubules contain spermatozoa.

The **vesiculæ seminales** are glandular structures, consisting on each side of a main part, with several accessory parts, each part being composed of a convoluted tubule of considerable length when unravelled. The duct joins the corresponding vas deferens. The tubules are lined by long columnar epithelium. Their convolutions are held together by connective tissue containing many blood-vessels and cleft-like lymphatics (fig. 544). Between the bases of the epithelium-cells is a row of bladder-like cells occupied by clear fluid and having a very characteristic appearance in stained sections. The columnar cells yield a secretion which is poured out from them in the form of droplets which accumulate to form a clear or opalescent fluid filling the tubes. This fluid, in some animals (*e.g.* guinea-pig), has the property of coagulating when it is ejected into the vagina.

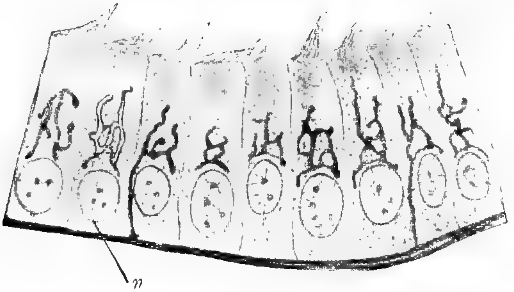


FIG. 542. CELLS OF EPIDIDYMIS, SHOWING CANALISATION OF THE CYTOPLASM. (E. Holmgren.)

n, nucleus. In two cells the canals extend to the basement-membrane.

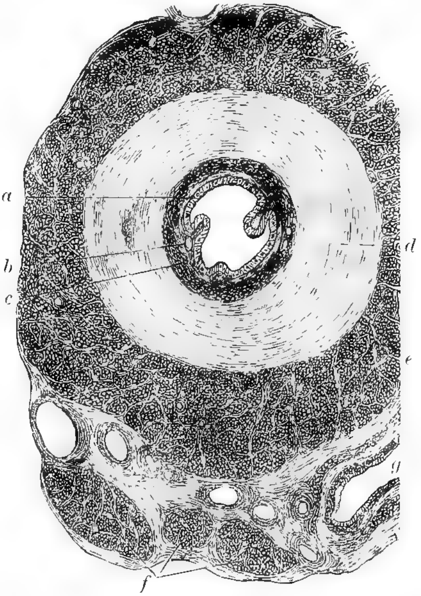


FIG. 543.—SECTION ACROSS THE COMMENCEMENT OF THE VAS DEFERENS. (Klein.)

a, epithelium; *b*, mucous membrane; *c*, *d*, *e*, inner, middle, and outer layers of the muscular coat; *f*, bundles of the internal cremaster muscle; *g*, section of a blood-vessel.

MICROSCOPIC STRUCTURE OF THE TESTICLE.

The intertubular tissue.—The connective tissue between the tubules of the testicle is generally of very loose texture, and contains numerous lymphatic clefts, which form an intercommunicating system of commencing lymphatic vessels. Lying in this intertubular tissue are strands of poly-

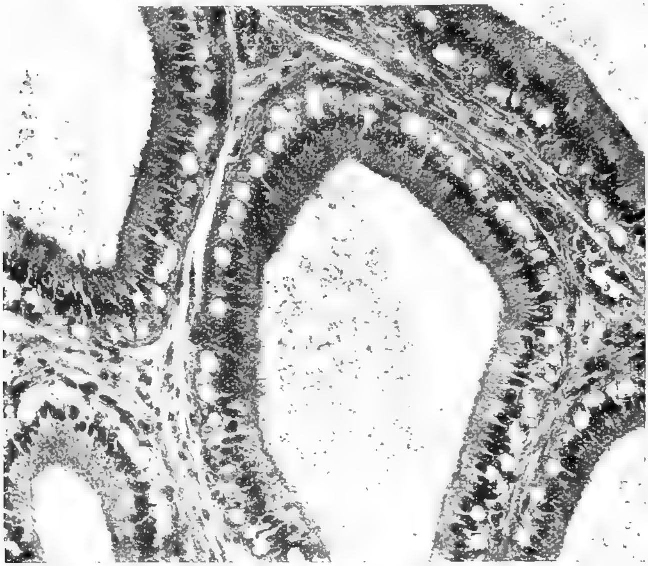


FIG. 544.—VESICULA SEMINALIS OF OX. Photograph. Magnified 200 diameters.
Drops of secretion are seen at the free ends of some of the cells.

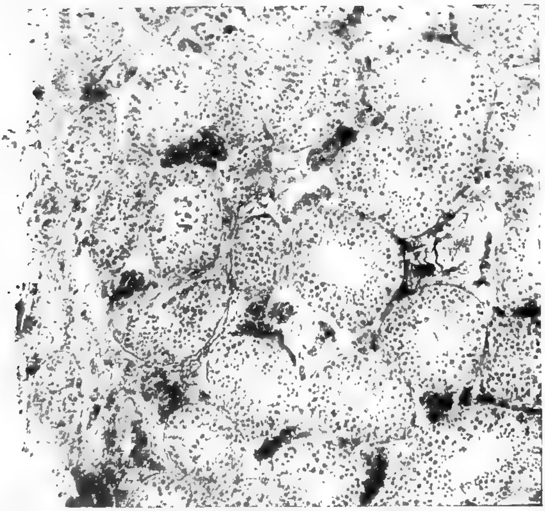


FIG. 545.—HUMAN TESTICLE. Magnified 50 diameters. Photograph.
From an iron-hæmatoxylin preparation by Prof. M. Heidenhain.
The masses of interstitial cells are stained dark in this section.

hedral epithelium-like cells (*interstitial cells*, figs. 545, 546, 547) of a yellowish colour; they are more abundant in some species of animals (cat, boar) than in others. They accompany the blood-vessels before these break up to form the capillary networks which cover the walls of the seminiferous tubules.

The interstitial cells contain in many animals yellowish-brown lipoid

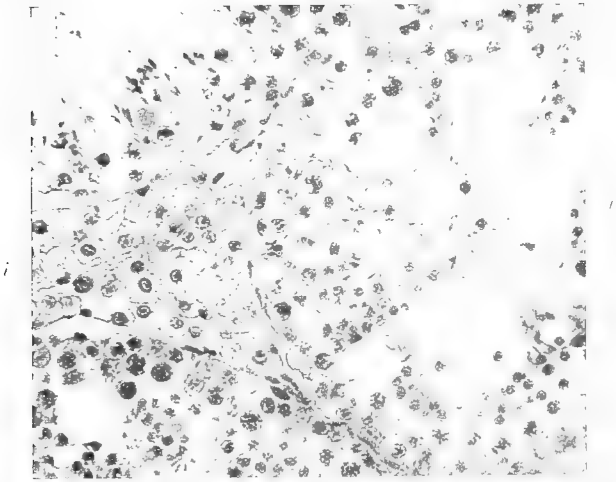


FIG. 546.—FROM A SECTION OF TESTICLE OF CAT. Photograph. Magnified 200 diameters. *t*, section of a tubule; *i*, interstitial cells, lying between three tubules.

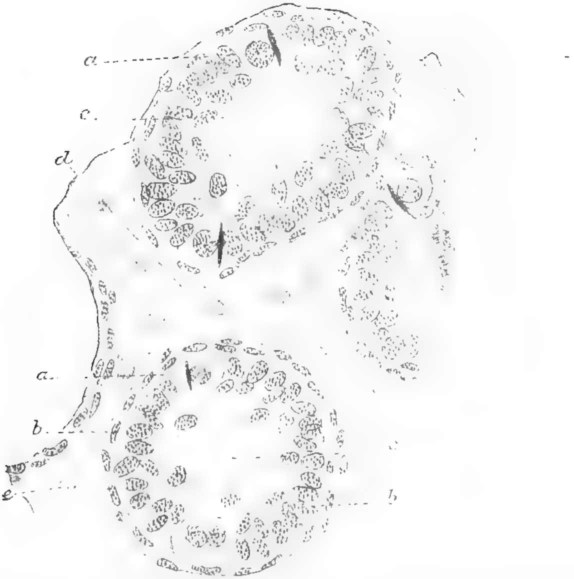


FIG. 547.—SECTION OF TESTICLE OF A BOY OF NINE YEARS OLD. Highly magnified. (Spangaro.)

a, enlarged cells (spermatogonia), some of them dividing; several contain crystals (Lubar's crystals); *b*, cells lining the tubule; *c*, coagulated contents of tubule; *d*, interstitial tissue; *e*, mast-cells.

or fatty globules (staining with osmic acid), and sometimes needle-shaped crystals (protein). Similar fatty globules may occur in the Sertoli cells of the seminiferous tubules; they are believed to pass into those cells from the interstitial tissue.

The **seminiferous tubules.**—The seminiferous tubules are formed of a connective-tissue membrane, which has a lamellar structure. The lamellæ are covered by flattened cells; fibres, chiefly elastic, occupy the substance of each lamella. In the adult the tubules contain several layers of epithelium-cells, but in the child there is no clear distinction into layers, the cells being all more or less similar (fig. 547). Of the layers seen in the tubules of the adult testicle, the one next to the basement-membrane is a stratum of clear cubical cells (*spermatogonia* or *spermatogons*, fig. 548), the nuclei of which for the most part exhibit the irregular network which is characteristic of the resting condition, but in some tubules show indications of division. Here and there between the spermatogonia some of the lining epithelium-cells are enlarged, and project between the more internal layers, being

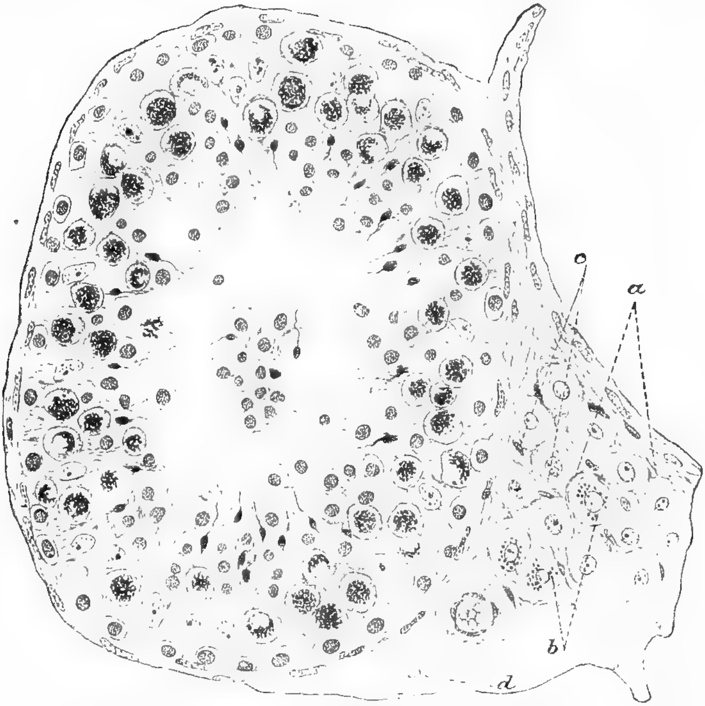


FIG. 548.—SECTION FROM THE TESTICLE OF A MAN 42 YEARS OLD. Magnified about 350 diameters. (Spangaro.)

d, interstitial cells; *b*, some containing pigment; ***c***, nuclei of ordinary connective-tissue cells; *d*, mast-cell. In the section of the tubule may be seen in succession from without in, spermatogonia, spermatocytes, spermatids, and spermatozoa. A few spermatids and spermatozoa are detached and occupy the middle of the tubule.

connected with groups of developing spermatozoa. These enlarged cells are the *cells of Sertoli* (fig. 552, *a'*, *a''* ; fig. 555).

Next to this lining epithelium is a zone of larger cells (*spermatocytes*, fig. 552, *b*), the nuclei of which are usually in some stage of hetero- or homo-typical mitotic division (see p. 16); these cells may be two or three deep (as in fig. 548, and in *a*, fig. 549). Next to them, and most internal, are to be seen in some tubules (fig. 548, and fig. 549, *b* and *c*) a large number of small protoplasmic cells with simple spherical nuclei (*spermatids*, fig. 552, *c*). In other tubules the spermatids are elongated, and the nucleus is at one end, and in others again these elongated cells are completely converted into spermatozoa, which lie in groups: their heads projecting between the deeper cells and connected with one of the Sertoli cells of the lining epithelium, and their tails emerging into the lumen of the tubule (fig. 549, *b*). As these spermatozoa become matured they gradually shift altogether towards the lumen, where they eventually become free (*c*) from the Sertoli cells. During the time that one set of spermatozoa has been forming, another set of spermatocytes is produced by the division of the spermatogonia, and after the discharge of the first set of spermatozoa the process of division of spermatocytes to form spermatids and development of spermatozoa from these is repeated as before (see diagram, fig. 552).

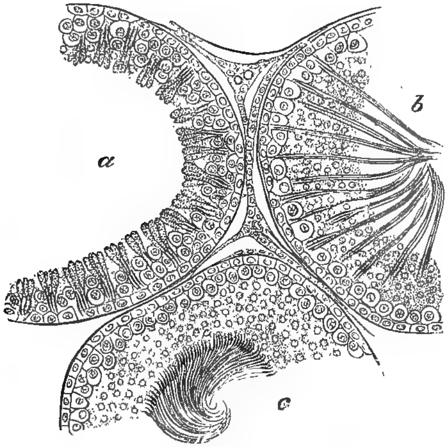


FIG. 549.

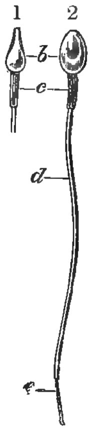


FIG. 550.

FIG. 549.—SECTION OF PARTS OF THREE SEMINIFEROUS TUBULES OF THE RAT, AS SEEN UNDER A LOW POWER.

a, with the spermatozoa least advanced in development; *b*, more advanced; *c*, containing fully developed spermatozoa. Between the tubules are seen strands of interstitial cells with blood-vessels and lymph-spaces.

FIG. 550.—HUMAN SPERMATOZOA. Magnified 1000 diameters. (G. Retzius.)

1, in profile; 2, viewed on the flat; *b*, head; *c*, middle-piece; *d*, tail; *e*, end-piece of the tail, which is described as a distinct part by Retzius.

The spermatids were termed *young spermatozoa* by H. H. Brown, from whose investigation of the subject the above account is mainly derived.

The **spermatozoa.**—Each spermatozoon (sperm) consists of three parts, a head, a middle part or body, and a long tapering tail (fig. 550). In man the *head* is of a pointed oval shape, somewhat flattened especially towards its apex; in some animals it bears a small barb-like projection at this extremity. The apical part is covered by a cap of a somewhat different appearance from the rest—the head-cap. The *middle-piece* is in man short and cylindrical, and has a spiral fibre passing round it. An axial fibre, itself fibrillated, passes from a knob close to the head right through the body and tail. The *tail* is the longest part of the spermatozoon, and when examined with the microscope in the fresh condition is seen to be in continual vibratile motion, the action resembling that of a cilium. The extremity of the tail (end-piece) forms a distinct part of the spermatozoon, and in some animals may split into two or three fibrils; these can also sometimes be traced along the whole length of the tail. Human spermatozoa are about 0·05 mm. ($\frac{1}{500}$ inch) long, the head and middle-piece each measuring about $\frac{1}{10}$th of this amount.

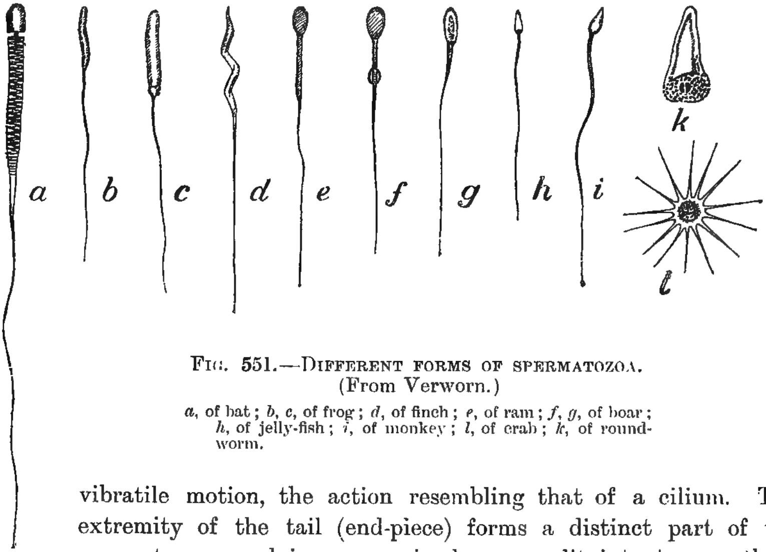


FIG. 551.—DIFFERENT FORMS OF SPERMATOZOA. (From Verworn.)

a, of bat; *b*, *c*, of frog; *d*, of finch; *e*, of ram; *f*, *g*, of boar; *h*, of jelly-fish; *i*, of monkey; *l*, of crab; *k*, of round-worm.

In different animals the shape of the head and the extent of middle-piece and tail vary greatly (fig. 551). In the rat (fig. 554, 7) the head is long, and is recurved anteriorly; it is set obliquely on the middle-piece. This is also of considerable extent, and has a closely wound spiral filament encircling it (H. H. Brown). In the newt the head is long and tapering, and the tail has a membranous expansion, attached in a spiral manner along its whole length. Such an expansion has also been described in the human spermatozoon, but its existence here is doubtful. In decapods, which possess no cilia, the spermatozoa are stellate and motionless (fig. 551, *l*); in nematoid worms they are amœboid (fig. 551, *k*). Sometimes two distinct kinds of spermatozoa are met with in the same species of animal, one kind being far the larger in size (giant spermatozoa) but much less numerous. Such giant spermatozoa have been observed in man.

Although the tail of the spermatozoon is usually considered to be a cilium, it exhibits, as we have seen, greater complexity of structure and is much more differentiated than ordinary cilia. Spermatozoa also differ from cilia in being highly resistant to putrefaction and to chemical reagents, including even strong acids and alkalies.

Spermatogenesis.—The spermatozoa are developed from the small cells (spermatids) which form the innermost stratum of the seminal epithelium, and these are themselves produced by the division of the large spermatocytes of the second layer.

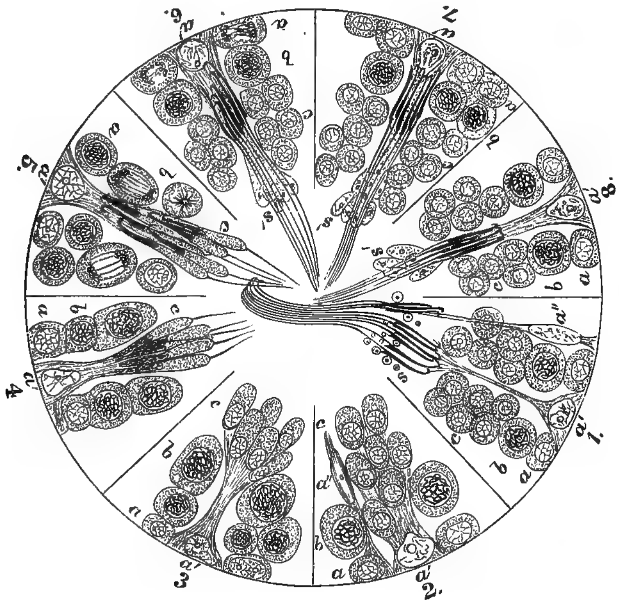


FIG. 552.—DIAGRAM EXHIBITING THE CYCLE OF PHASES OF SPERMATOGENESIS IN THE RAT.

a, lining epithelium-cells or spermatogonia, seen dividing in 6; *a'*, *a''*, Sertoli cells; *b*, spermatocytes, with skein-like nuclear filaments. These cells are seen actively dividing in 5. *c*, spermatids, forming an irregular column or clump in 6, 7, 8, and 1, and connected to an enlarged Sertoli cell, *a'*, of the lining epithelium in 2, 3, 4, and 5. In 6, 7, and 8 advanced spermatozoa of one crop are seen between columns of spermatids of the next crop. *s'*, parts of the spermatids which disappear when the spermatozoa are fully formed; *s*, seminal granules.

It is probable that fresh spermatocytes are formed by division of some of the lining epithelium-cells or spermatogons. The cycle of changes therefore which takes place is as follows: 1. Division of a lining epithelium-cell or spermatogon into two, one of which grows larger ("growing cells" of H. H. Brown), becomes a spermatocyte, and passes into the second layer, while the other remains in the first layer. 2. Division of the spermatocyte. 3. Further division of the daughter-spermatocytes thus produced. The four cells (spermatids) which result from this double division possess only one-half the somatic number of chromosomes in their nuclei, "reduction" having been effected in the final cell-divisions by which the spermatids are produced (p. 16). 4. Elongation of the spermatids and their gradual conversion into spermatozoa. As they undergo this conversion their grouping becomes more evident, and each group is found to be connected with a cell of Sertoli (fig. 552, *a'*; fig. 555); this probably ministers to their nutrition. The Sertoli cell undergoes a gradual process of elongation, so that the spermatozoa by the time they are fully developed are brought to the lumen of the tube, in which they then become free. In the mean-time other alternate groups of spermatids from which the next crop of spermatozoa will be derived are being formed in the same manner, passing through the same cycle of changes. So that different phases of development may be observed even in the same tubule, and in different tubules of the same testicle every phase may

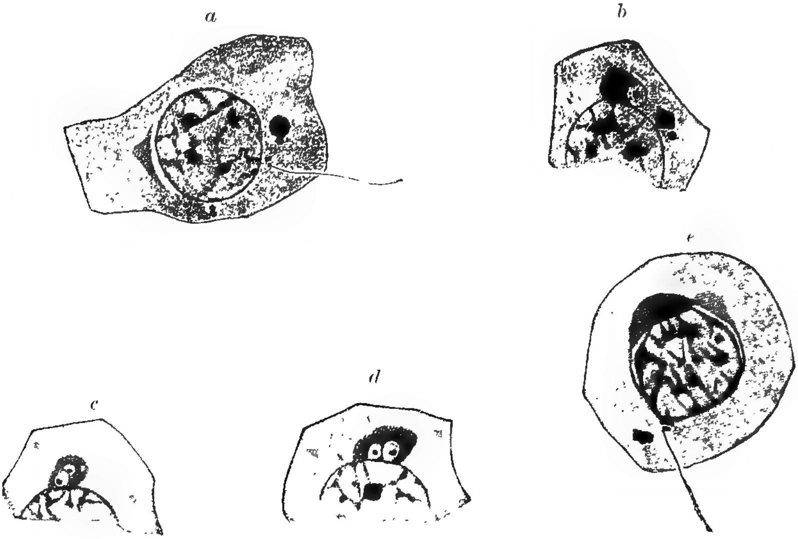


FIG. 553.—CHANGES IN THE SPERMATIDS IN THE COURSE OF FORMATION OF THE SPERMATOZOA. (Niessing.)

The tail-filament is seen (in *a* and *e*) to extend from the centrosome, which lies close to the nucleus. The head-cap (shown in *e*) is produced by a transformation of a special part of the archoplasm which becomes vacuolated (*b*, *c*, *d*).

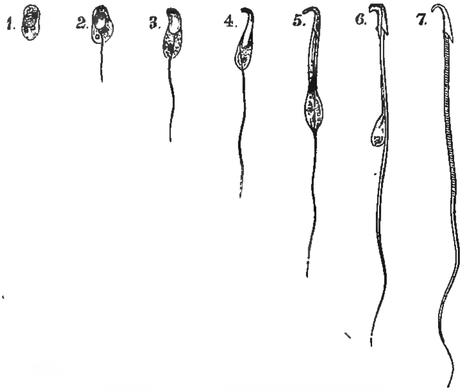


FIG. 554.—SPERMATOZOA FROM THE RAT IN DIFFERENT STAGES OF DEVELOPMENT. (H. H. Brown.)

1-6, developing spermatozoa from the testicle; 7, a mature spermatozoon from the vas deferens. The remains of the protoplasm of the cell, which is seen in 6 still adhering to the middle-piece of the spermatozoon and containing a number of chromatin granules, appears to be thrown off as the spermatozoon matures.

be traced. The accompanying diagram (fig. 552), which is constructed from H. H. Brown's drawings, illustrates the cycle of changes above described ; it is divided into eight parts, each of which shows the condition of the epithelium of a seminiferous tubule at a particular stage.

Each spermatid becomes converted into a spermatozoon in the following manner (figs. 553, 554). The nucleus forms the chief part of the head, while the tail develops as an outgrowth of the centrosome and cytoplasm. The tail-filament appears within the protoplasm, growing out from the centriole of the cell, which lies close to the nucleus (fig. 553). The centriole is double ; one of its two particles forms an annular expansion or ring, which, as development proceeds, moves down the tail-filament until it reaches the place where this leaves the cytoplasm : here it ultimately forms the limit of the body or middle-piece of the spermatozoon. The archoplasm (see p. 9) assists in forming the head of the spermatozoon ; a portion (the *idiozome* of Meves) at an early stage separates from the rest, lying apically to the nucleus. Within this portion vacuoles form (fig. 553, *b*, *c*, *d*) which presently run together into a clear non-stainable globule which flattens out over the nucleus and forms (fig. 553, *e*) the head-cap of the spermatozoon ; as development proceeds this may become indistinguishable from the rest of the head. The spiral fibre of the middle-piece is developed from mitochondria in the spermatid (see fig. 7, p. 5). A portion of the protoplasm of each spermatid containing a number of chromatin-particles (seminal granules) becomes detached and disintegrated before the spermatozoon is fully matured (fig. 552, *s*, *s′*).

A few spermatocytes undergo incomplete division ; the resulting spermatids are large (giant spermatids) and contain either one large nucleus or two or more nuclei which ultimately blend to form the head of the spermatozoon. In these cases a corresponding number of centrosomes is seen ; from each of these centrosomes a tail-filament may become developed.

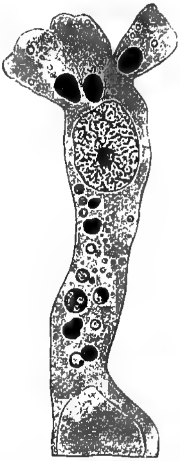


FIG. 555.—A CELL OF SERTOLI WITH WHICH THE SPERMATIDS (THREE OF WHICH ARE SHOWN) ARE BEGINNING TO BE CONNECTED : HUMAN. (Bramman.)

The cell contains globules staining with osmic acid ; similar but smaller globules are also seen in the spermatids. The "ring" formed around the tail-filament by one of the particles of the centrosome (see text) is shown in each of these spermatids close to the "head."

LESSON XXXVIII.

GENERATIVE ORGANS IN THE FEMALE.

1. Sections of ovary of (*a*) non-pregnant and (*b*) pregnant rabbit or cat. If from a pregnant animal the organ will be largely occupied by corpora lutea. Study the sections with a low power, observing the small and large Graafian follicles, each enclosing an ovum, scattered through the stroma; also the corpora lutea. Measure Graafian follicles of different sizes. Make a general sketch of a section under the low power. Then sketch carefully one or two of the follicles with their contents under a high power.

2. Take the fresh ovary of a sheep and with a needle or fine scalpel-point prick one of the largest and most prominent of the Graafian follicles. The organ must be held just over a slide so that on pricking the follicle the fluid contents may spurt out on to the glass. Examine the drop of liquor folliculi with a low power for the escaped ovum, which will be surrounded by follicular cells. When found place a piece of a thick hair in the drop, cover with cover-glass and examine with high power.

3. Section across Fallopian tube. Sketch a section under the low power.

4. Section across the body of the uterus of a child, or across a cornu of a bicorned uterus of a cat or rabbit. Observe the thickness of the muscular and mucous coats respectively. Notice the (ciliated) columnar epithelium lining the organ and extending into the glands of the mucous membrane. Draw a part of a section under the low power.

5. Section of placenta. Notice the venous spaces occupied by maternal blood, and within the spaces sections of the fœtal villi.

6. Section of vagina. Notice the stratified epithelium which lines it and which is continued over the projecting part of the os uteri. If the section is taken through the anterior wall, the urethra will be included in it.

THE OVARY.

The **ovary** is a small solid organ, mainly composed of a *stroma* of fibrous tissue, with many spindle-shaped cells, particularly abundant in the human ovary (fig. 559). It also contains, near its attachment to the broad ligament, a number of plain muscular fibres, and receives here numerous and large blood-vessels. It is covered by a layer of small columnar epithelium-cells (*germinal epithelium*), between which may here and there be seen a few larger spheroidal cells, with large round nuclei. In the young subject the epithelium occasionally dips down into the subjacent stroma (fig. 562).

Scattered throughout the stroma are vesicles of different sizes, the smallest being near the surface of the organ, the larger ones placed more deeply in the stroma, although, as they increase in size, they extend towards the surface (fig. 556).

These vesicles are the *Graafian follicles.* Each Graafian follicle has a proper wall (*theca folliculi*) formed of a layer derived from the stroma, with a special inner layer containing large cells: both strata are highly vascular. Each follicle contains an *ovum* and *epithelium.* In the smallest follicles the ovum is small, and the epithelium of the follicle is formed of a single layer of cells which may be flattened against the ovum (figs. 559, 562). In somewhat larger follicles the epithelium-cells are in two layers, and are columnar in shape (fig. 561, E). In still larger ones, each of the two layers is formed of several strata of cells, and fluid has begun to collect between the layers at

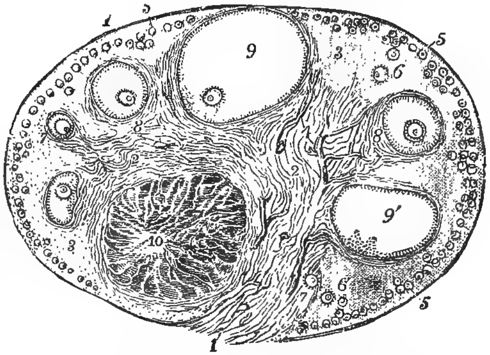


Fig. 556.—Section of the ovary of the cat. Magnified 9 diameters. (Schron.)

1, outer covering and free border of the ovary; 1′, attached border; 2, the central ovarian stroma showing a fibrous and vascular structure; 3, peripheral stroma; 4, blood-vessels; 5, Graafian follicles in their earliest stages lying near the surface; 6, 7, 8, more advanced follicles which are embedded more deeply in the stroma; 9, an almost mature follicle containing the ovum in its deepest part; 9′, a follicle from which the ovum has fallen out in preparing the section; 10, corpus luteum.

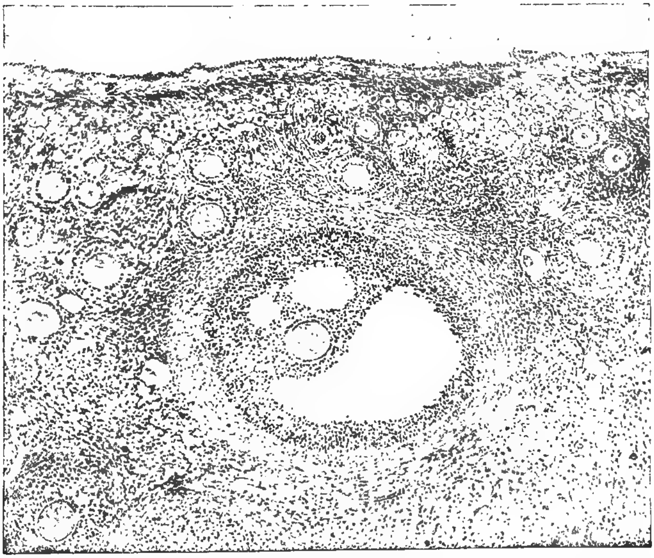


Fig. 557.—Section of ovary of rabbit. Photograph. Magnified 60 diameters.

One large Graafian follicle and a number of smaller follicles are seen, the smallest forming a layer near the surface. Notice the tunica albuginea covering the surface; itself covered by columnar epithelium.

one part. Of the two layers, the one which lines the cavity of the follicle is termed the *membrana granulosa*, while the mass of cells which more immediately surrounds the ovum is known as the *cumulus* or *discus proligerus* (fig. 557).

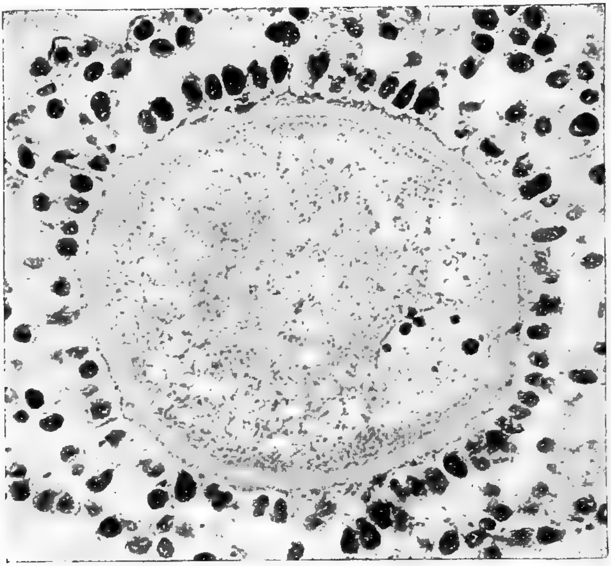


FIG. 558.—OVARIAN OVUM OF RABBIT. Photograph. Magnified 400 diameters.

The ovum is enclosed within a clear thick membrane (zona pellucida) outside of which, and adhering to it, are epithelium-cells of the Graafian follicle. The protoplasm of the ovum shows numerous fine granules and a certain number of large clear yolk globules. The nucleus or germinal vesicle lies near the periphery: it contains several globules of chromatin, the largest of which is the nucleolus or germinal spot.

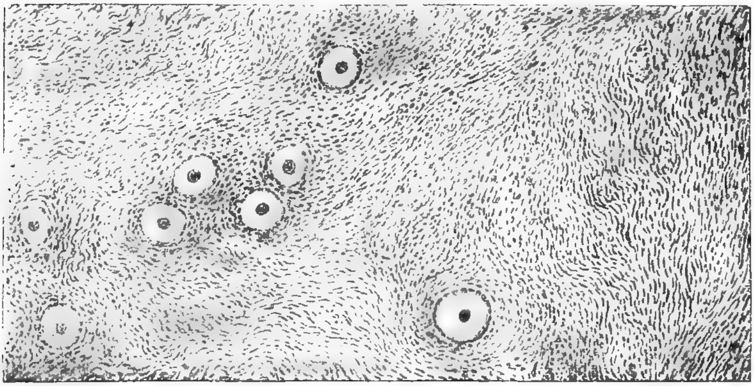


FIG. 559.—SECTION OF PART OF HUMAN OVARY SHOWING SMALL GRAAFIAN FOLLICLES EMBEDDED IN A FIBRO-CELLULAR STROMA. (Sellheim.)

In the largest follicles the fluid has much increased in amount, so that the follicle has become gradually larger and more tense. Finally it reaches and projects from the surface of the ovary; here it eventually bursts, and the liquor folliculi, with its contained ovum, is set free. This event is believed to occur usually at some time during menstruation.

Some of the Graafian follicles do not burst, but, after attaining a certain stage of maturity, undergo a process of retrograde metamorphosis and eventually disappear.

The **ovarian ova** or **oocytes** are large spherical cells, about 0·2 mm. ($\frac{1}{125}$ inch) in diameter. When fully formed (fig. 558), as in the largest Graafian follicles, each ovum is surrounded by a thick transparent membrane (*zona pellucida*). Within this is the protoplasm of the oocyte (*vitellus*), filled with fatty and albuminous granules (yolk granules). Lying in the vitellus, generally eccentrically, is the large clear round nucleus (*germinal vesicle*), which invariably has a well-marked nucleolus (*germinal spot*), sometimes more than one.

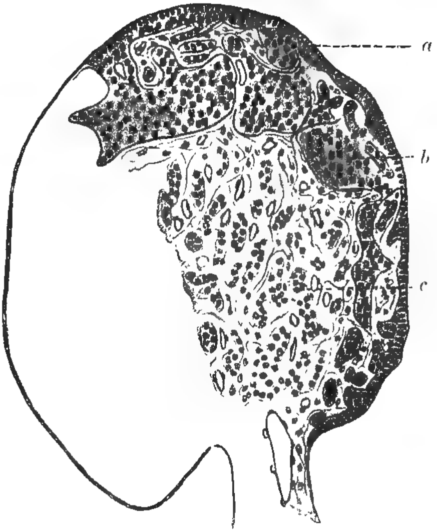


FIG. 560.—OVARY OF 28-DAY RABBIT, SHOWING THICKENED GERMINAL EPITHELIUM GROWING INTO STROMA. (Felix and Bühler.)

a, germinal epithelium; *b*, a thickened downgrowth from this epithelium; *c*, stroma of ovary.

Oogenesis.—Both the ova and the epithelium of the Graafian follicles originate from the germinal epithelium of the embryo. This forms at first a simple layer covering the stroma, but later becomes thickened and multiple. After a time rounded cords of epithelium-cells (*egg-tubes* of Pflüger, fig. 560; fig. 561, A) grow down into the stroma, whilst this at the same time grows into the thickened epithelium. The cords presently become broken up by ingrowths of stroma into isolated nests of epithelium cells (fig. 561, B), each of which may be taken to represent a Graafian follicle. Some of the cells become enlarged to form primitive ova; usually there is one such enlarged cell in each nest. The remaining cells form the epithelium of the follicle (fig. 561, C). It would appear that the protoplasm of the ovum remains connected with the cells of the discus proligerus by fine processes which pass through pores in the zona pellucida, while on the other hand the epithelium-cells of the follicle are themselves interconnected by protoplasmic bridges, so that the whole forms a kind of syncytium.

The stroma of the ovary contains, besides the spindle-shaped connective-tissue cells and plain muscular fibres already mentioned, a number of epithelium-like *interstitial cells.* Some of these are stated to have been derived from the germinal epithelium (Lane-Claypon); others have originated from cells of old *corpora lutea.*

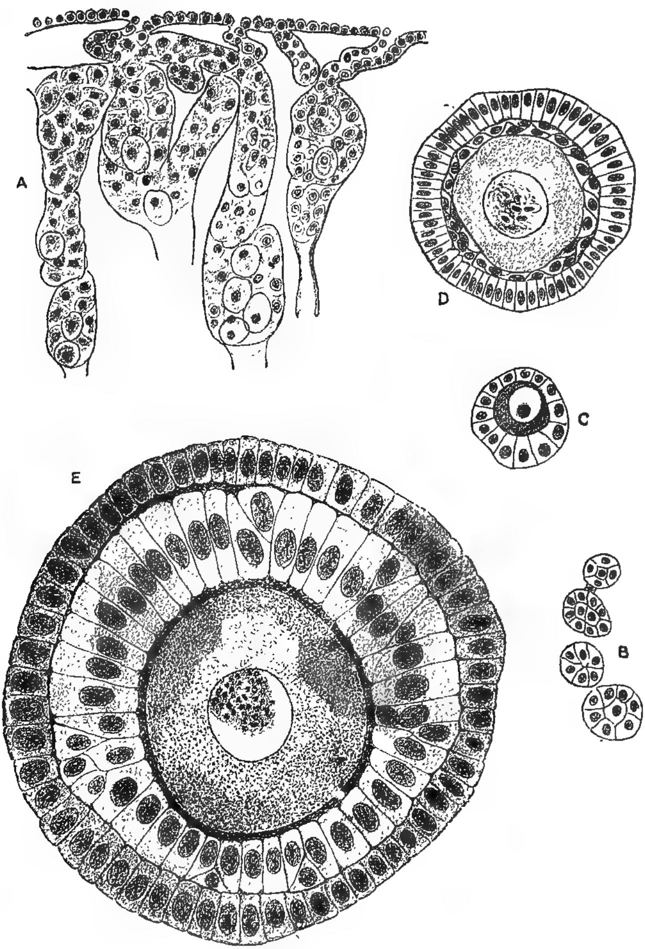


Fig. 561.—Figures showing various stages in the development of the Graafian follicles of the rabbit.

A, from ovary of young rabbit, showing "egg-tubes" of Pflüger growing in from germinal epithelium; some of the tubes contain primitive ova; *B*, primitive Graafian follicles formed from the breaking up of an egg-tube; *C*, a young Graafian follicle, with a single layer of follicle-epithelium; *D*, a somewhat older follicle, with the second layer forming within the first; *E*, a more advanced follicle, showing two complete layers of columnar epithelium surrounding the ovum within the follicle.

Vessels and nerves.—The blood-vessels of the ovary are very large and numerous. The smaller vessels are abundantly distributed in the walls of the Graafian follicles, over which they form a close network. The ovary also receives many nerve-fibres, but their ultimate destination is not known.

Corpora lutea.—These are yellowish nodules, which are developed out of the Graafian follicles after the ova have been extruded. They consist of columns of large cells containing lipoid globules (*luteal cells*), with intervening trabeculæ of vascular fibrous tissue. In most animals the trabeculæ converge to a central strand of connective tissue occupying the axis of the nodule (fig. 565). The columns of cells are not unlike those of the cortex of the suprarenal capsule. In the human subject the cells of the corpus luteum are massed into plaits or folds, arranged perpendicularly to the wall of the follicle, with vascular connective tissue in the interspaces. Numerous capillary blood-vessels, of a sinus-like character, ramify amongst the luteal cells; the latter probably yield an internal secretion to the blood.

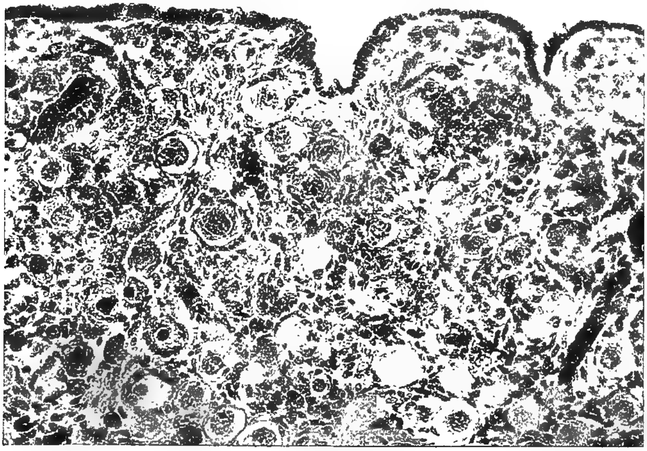


FIG. 562.—SECTION OF OVARY OF HUMAN FŒTUS, SHOWING NUMEROUS PRIMITIVE GRAAFIAN FOLLICLES EMBEDDED IN THE STROMA. Photograph. Magnified 200 diameters.

Each primitive Graafian follicle consists of a primitive ovum surrounded by a single layer of flattened follicular epithelium-cells.

The corpus luteum is derived from the wall or theca of the follicle, which becomes thickened and folded by multiplication and hypertrophy of its cells. These grow into the empty follicle in the form of intercommunicating trabeculæ, between which connective tissue and blood-vessels pass in from the vascular wall of the follicle converging along with the trabeculæ towards the centre of the follicle, where the remains of a blood-clot long continue to be visible. Ultimately, however, the centre becomes occupied by a kind of scar tissue, which may be continued to the surface of the ovary at the point where the rupture of the follicle originally occurred. Sometimes there is no clot in the follicle, its cavity being at first occupied by lymph, and the luteal cells grow into this. After persisting for a time the corpus luteum

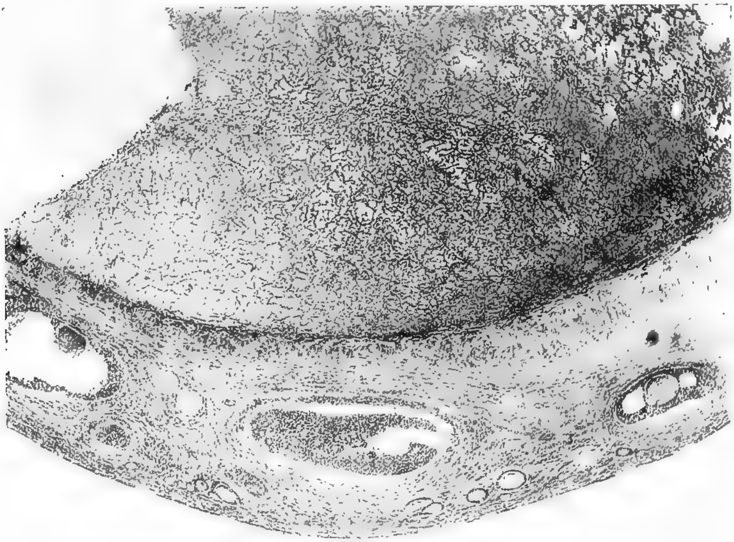


Fig. 563.—Section of a Graafian follicle of the rabbit which has recently ruptured. Photograph. Magnified 50 diameters.

The ovum and follicular epithelium have become entirely extruded and the follicle is occupied by a blood-clot.

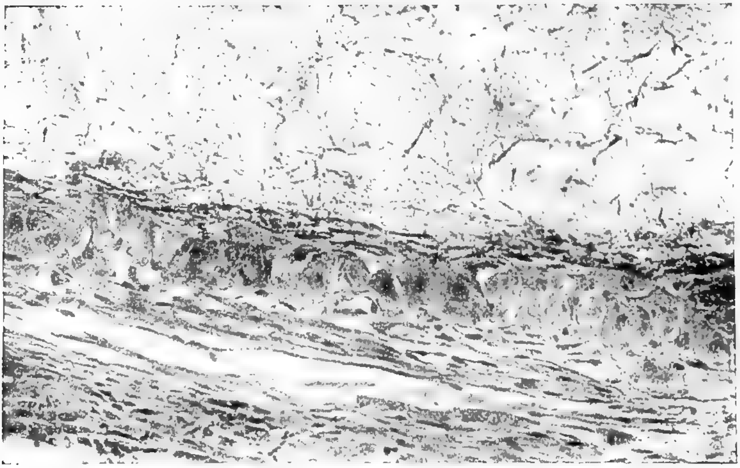


Fig. 564.—Part of the above section. Photograph. Magnified 200 diameters.

The figure shows the fibrous wall (theca) of the follicle containing enlarged cells in its thickness. The complete disappearance of the follicular epithelium is obvious. The cavity of the follicle is occupied by a coagulum of blood, the network of fibrin-filaments being well displayed.

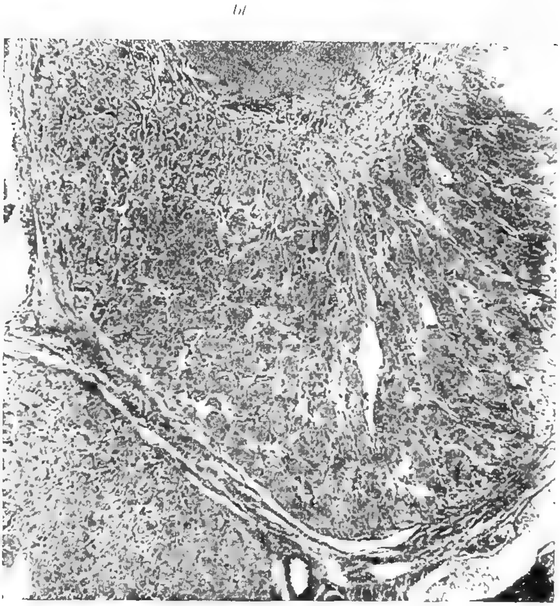


Fig. 565.—Corpus luteum of rabbit formed of trabeculæ of large luteal cells which have developed from the cells of the theca. Photograph. Magnified 60 diameters.

The remainder of the original blood-clot (*bl*) is still seen near the middle of the corpus luteum. Just below this is a kind of cicatricial fibrous tissue formed by organisation of part of the clot.

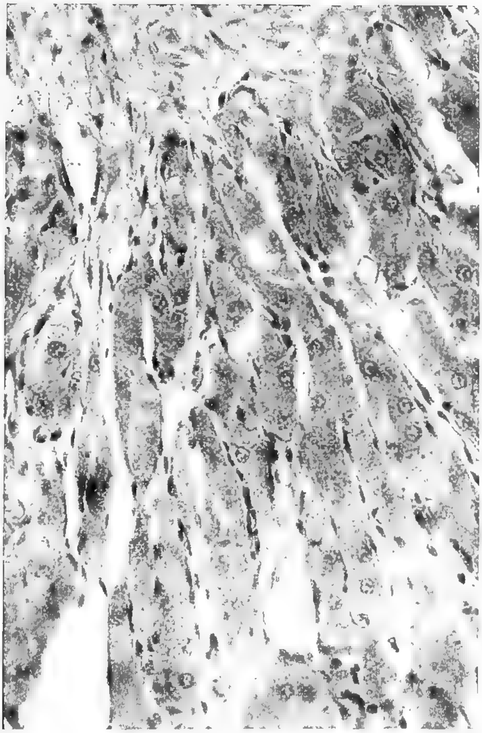


Fig. 566.—A part of the section shown in the above figure. Photograph. Magnified 200 diameters.

The columns of luteal cells and the cicatricial tissue to which they converge are well seen in this figure.

gradually disappears, its cells becoming merged into those of the surrounding stroma. Corpora lutea grow much larger and remain much longer persistent in the event of pregnancy supervening.

THE FALLOPIAN TUBES AND UTERUS.

The **Fallopian tubes** or **oviducts** are lined by a very vascular mucous membrane which is covered with ciliated epithelium, and has numerous longitudinal folds or rugæ with depressions between (fig. 567). Externally the tube is covered by a serous coat, within which is a thin longitudinal stratum of plain muscular fibres overlying circular fibres of the same tissue; these layers are not distinctly marked off from one another.

The Fallopian tubes commence near the ovary with an open end, the margins of which are spread out into a number of processes termed *fimbriæ*.

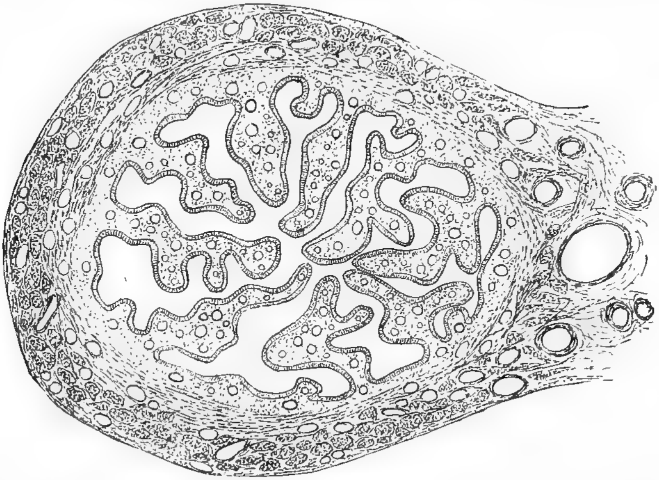


Fig. 567. Section across the Fallopian tube. (Somewhat diagrammatised.)

One or two of these fimbriæ are directly attached to the surface of the ovary in the manner shown in fig. 568. Each Fallopian tube terminates distally in the uterus; opening, in the human subject, at the upper angles of the body of the uterus. In animals which possess a bicorned uterus, the Fallopian tube is directly continued into the corresponding cornu.

The human **uterus** is composed of two parts, the body and cervix. The body is formed of the following layers (fig. 569):—

1. A *serous layer*, derived from the peritoneum, which covers the greater part of the fundus.

2. A *muscular layer*, which is of great thickness and is formed of plain muscular fibres disposed in three, more or less blended, strata. Of these the outer is thin and has its fibres arranged partly longitudinally, partly circularly. The middle, on the other hand, is thick; its fibres run in different directions,

and it contains the ramifications of the larger blood-vessels. The inner layer, again, is thinner and has both longitudinal and circular fibres, many of the latter being prolonged internally into the deeper part of the mucous

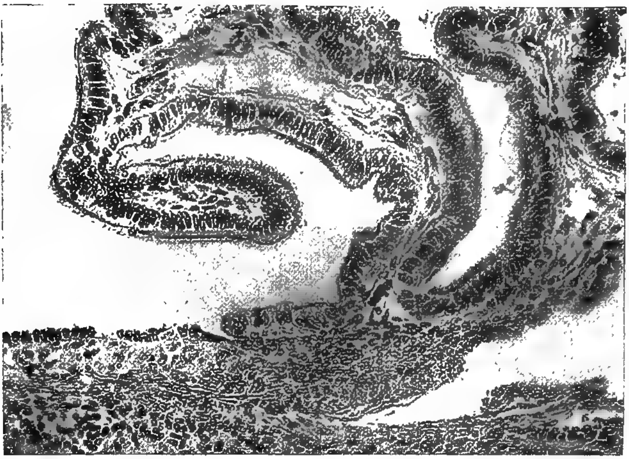


FIG. 568.—SECTION OF OVARY OF GUINEA-PIG AT THE PLACE OF ATTACHMENT OF THE FIMBRIATED END OF THE FALLOPIAN TUBE. Photograph. Magnified 200 diameters.

Notice the ciliated epithelium covering the fimbriæ, continued into the much smaller non-ciliated cells of the ovarian surface. Observe also the numerous and large blood-vessels of the fimbriæ.

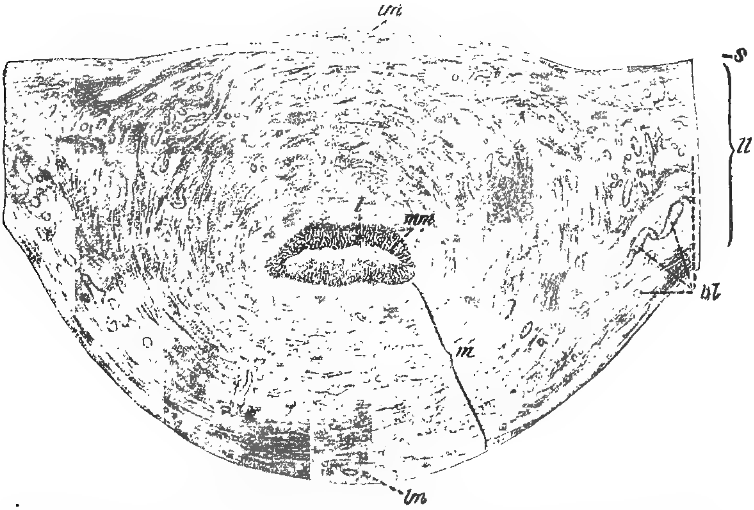


FIG. 569.—SECTION OF HUMAN UTERUS. (Sobotta.) Twice the natural size.

s, serous layer; *lm*, longitudinal muscular fibres; *m*, circular muscle; *mm*, mucous membrane; *l*, cavity of uterus; *ll*, broad ligamentum latum; *bl*, blood-vessels.

membrane; the extremities of the uterine glands extend between and amongst the muscle-fibres.

3. A *mucous membrane* (fig. 569, *mm*), composed of soft connective tissue containing a large number of spindle-shaped cells. It is lined by ciliated epithelium and contains long, simple, tubular glands, which take a curved or convoluted course in passing through the membrane (fig. 570, *gl*, and fig. 571). Their epithelium is continuous with that which covers the inner surface of the mucous membrane and is also ciliated for some distance within the glands. In the cervix the mucous membrane is marked by longitudinal and oblique ridges; the glands are shorter but more complex than those of the body of the uterus, and are lined by columnar mucus-secreting cells. Near the os uteri the epithelium becomes non-ciliated columnar; at the margin of the os uteri this passes into a stratified epithelium which overlies vascular papillæ of the corium. The mucous membrane is very vascular; it also contains a large number of lymph-vessels.

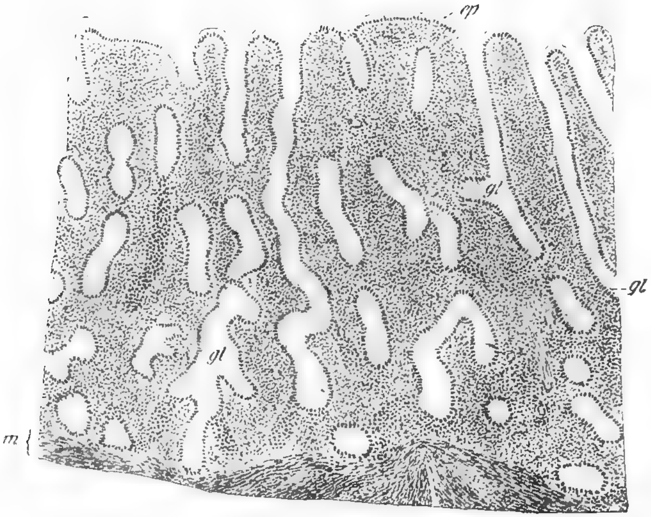


FIG. 570.—SECTION OF THE UTERINE MUCOUS MEMBRANE. (Sobotta.) Magnified 150 diameters.

ep, epithelium of cavity; *gl*, glands; *m*, muscularis.

In those animals the uterus of which is composed of two cornua, the arrangement of the muscular tissue is simpler than in the human uterus (which was originally double in the embryo and has been formed by the fusion of two such tubes). Fig. 571 exhibits the structure of a cornu of the uterus of the rabbit showing the convoluted glands extending through the mucous membrane; the thick innermost muscular layer which occupies the deepest part of the mucosa; the large blood-vessels in the submucous layer, and the two strata of the true muscular tissue outside the main vessels.

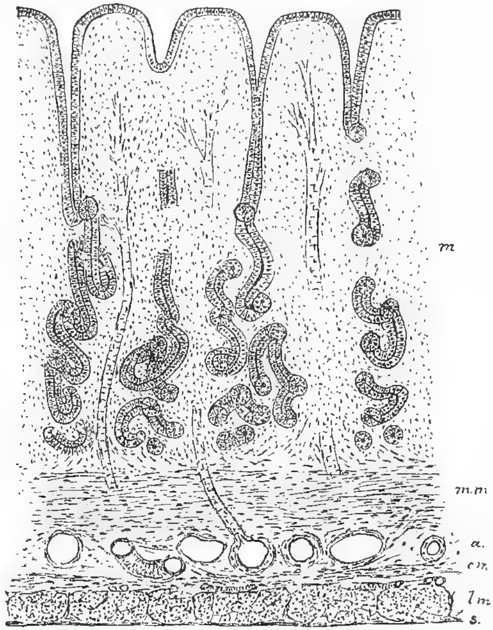


FIG. 571. SECTION OF A CORNU OF THE RABBIT'S UTERUS.

s, serous layer; *l.m.*, longitudinal muscular fibres; *c.m.*, circular muscular fibres of the muscular coat; *a*, areolar tissue with large blood-vessels; *m.m.*, muscularis mucosæ; *m*, mucous membrane.

Changes accompanying menstruation.—At the commencement of each menstrual period the mucous membrane of the uterus undergoes a partial process of disintegration accompanied by an escape of blood from the capillaries of the membrane (fig. 572). This is succeeded by a rapid renewal of the disintegrated part. Should pregnancy supervene, the process of renewal results in the formation over certain parts of a greatly thickened mucous membrane, with long convoluted glands; this is known as the *decidua*. The muscular layer also becomes enormously hypertrophied during pregnancy; this hypertrophy is produced by the enlargement of the individual muscle-cells.

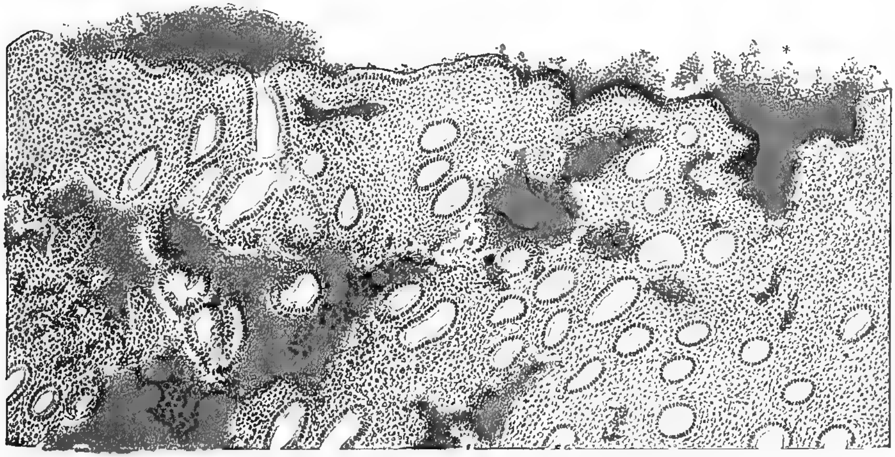


FIG. 572.—SECTION OF MUCOUS MEMBRANE OF HUMAN UTERUS DURING MENSTRUATION, SHOWING MASSES OF BLOOD WHICH HAS ESCAPED FROM RUPTURED CAPILLARIES INTO THE INTERGLANDULAR TISSUE, AND HAS AT ONE PLACE (✱) BROKEN THROUGH THE SURFACE EPITHELIUM. (Sellheim.)

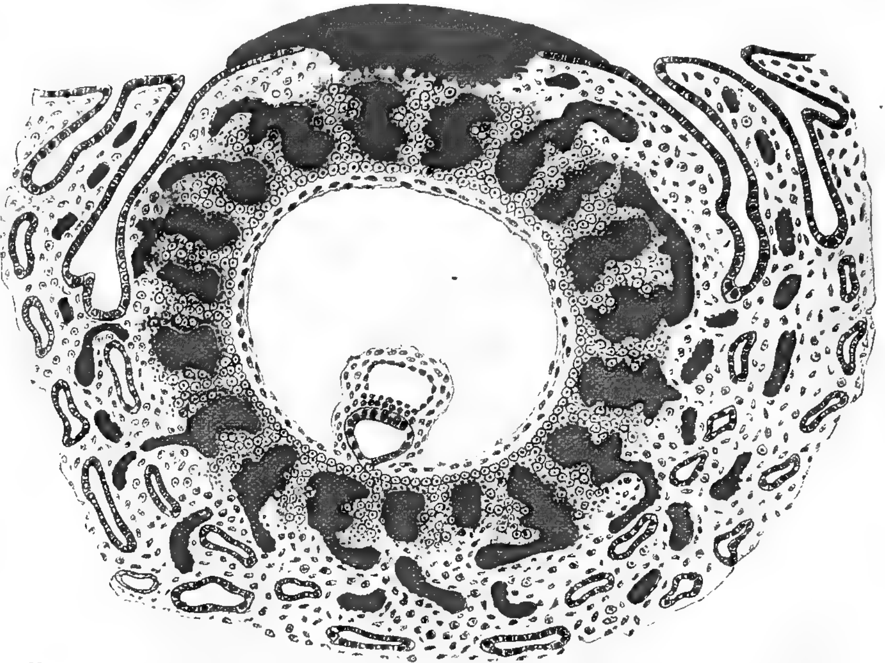


FIG. 573.—DIAGRAM TO ILLUSTRATE THE EMBEDDING OF THE OVUM IN THE DECIDUA AND THE FIRST FORMATION OF THE FŒTAL VILLI IN THE FORM OF A SYNCYTIAL TROPHOBLAST (DERIVED FROM THE OUTER LAYER OF THE OVUM) WHICH IS INVADING SINUS-LIKE BLOOD-SPACES IN THE DECIDUA. (T. H. Bryce.)

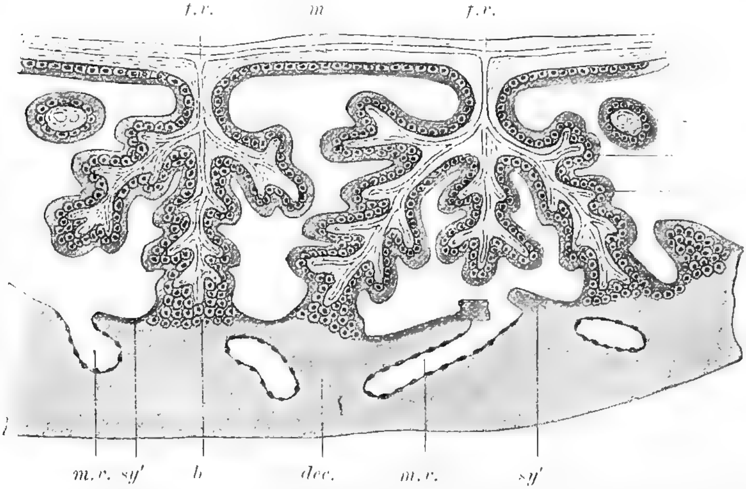


FIG. 574.—DIAGRAM OF A FURTHER STAGE IN THE FORMATION OF THE PLACENTA, SHOWING THE FŒTAL VILLI WITHIN THE BLOOD-SPACES OF THE PLACENTA AND PARTLY ATTACHED TO THE DECIDUAL WALL. (T. H. Bryce.)

The villi are now occupied by a core of vascular mesoderm. They are covered by a syncytium (continued over the decidua), within which is a layer of epithelium-cells; *f v.*, fœtal vessels; *m.v.*, maternal vessels; *m*, mesoderm of chorion; *a*, a villus cut across; *b*, attachment of a villus; *sy*, syncytial covering to villi continued at *sy'* on to decidua; *ep*, epithelial layer under syncytium.

The phenomenon of *heat* in animals is attended by changes in the uterus which are analogous to those occurring during menstruation in the human subject. The whole series of alterations which accompany this condition—including the changes preparatory, accompanying, and succeeding the periodical blood-flow from the uterus—is known as the *œstrous cycle.*

Structure of the placenta.—When the developing ovum reaches the uterus it becomes embedded in the thickened mucous membrane (decidua). Processes (fœtal villi), formed at first entirely of epithelial-cells, partly distinct, partly conjoined into a syncytium, grow out into the decidua from the chorion which forms the external covering of the developing ovum (fig. 573). Later, vascular mesoderm from the chorion penetrates everywhere into the villi bringing fœtal blood from the umbilical vessels. In the meantime large blood sinuses become formed in the decidua, and into these maternal blood is poured by small spiral arteries, and is taken away by corresponding veins. The fœtal villi are therefore bathed in maternal arterial blood within the sinuses of the decidua (fig. 574), into which for the most part they hang free, although some are attached to the wall of the decidua and others to fibrous septa which extend from this wall to the chorion, and partly subdivide the placenta into loculi.

A section across the discharged placenta or afterbirth shows it to be bounded on the fœtal side by the chorion, covered by the smooth amnion, and on the maternal side by the thin and somewhat uneven detached part of the decidua—a separation having occurred in the substance of the decidua when the placenta becomes detached from the uterus. Between these two boundaries is a spongy mass which in sections examined under the microscope (fig. 575) appears to be formed of a more or less continuous blood-space in which an enormous number of fœtal villi are seen, cut in various directions. Each villus (fig. 576) is formed of jelly-like connective tissue covered by a layer of epithelial-cells, which appear to be united with one another to form a syncytium. Within the larger villi arterioles and venules are seen and in some capillaries also; within the smaller only capillaries. Sometimes villi are observed which appear to be undergoing fibrinous degeneration (fig. 575).

THE CLITORIS, VAGINA AND URETHRA.

The **clitoris** is similar in structure to the penis, being mainly composed of erectile or cavernous tissue arranged in structures corresponding generally with the corpora cavernosa and corpus spongiosum but much less developed. There are also two oval masses of erectile tissue, one on each side of the vaginal orifice; as well as an intermediate collection of plexiform veins which join these masses with the corpus spongiosum. The clitoris is not traversed by the urethra as in the male organ.

The **vagina** is lined by a mucous membrane furnished with a low stratified *epithelium* (*a*) with broad microscopic papillæ. Outside the epithelium is the *corium* (*b*) composed of a very vascular, dense, connective tissue. There are no glands in the mucous membrane. Outside the corium is a well-marked *muscular coat* (*c*) formed of plain muscle, the fibres having mainly a longitudinal direction. They are continued from the fibres of the uterus. Outside the muscular coat is a *fibrous layer.*

Bartolin's glands, which correspond with Cowper's glands in the male, lie on each side of the vagina near its upper end. Their ducts open immediately at the side of the orifice of the vagina. Bartolin's glands are of the compound racemose type, with mucous alveoli, lined with clear columnar cells.

The **urethra** in the female runs from the bladder parallel with the anterior wall of the vagina, with the fibrous layer of which it more or less

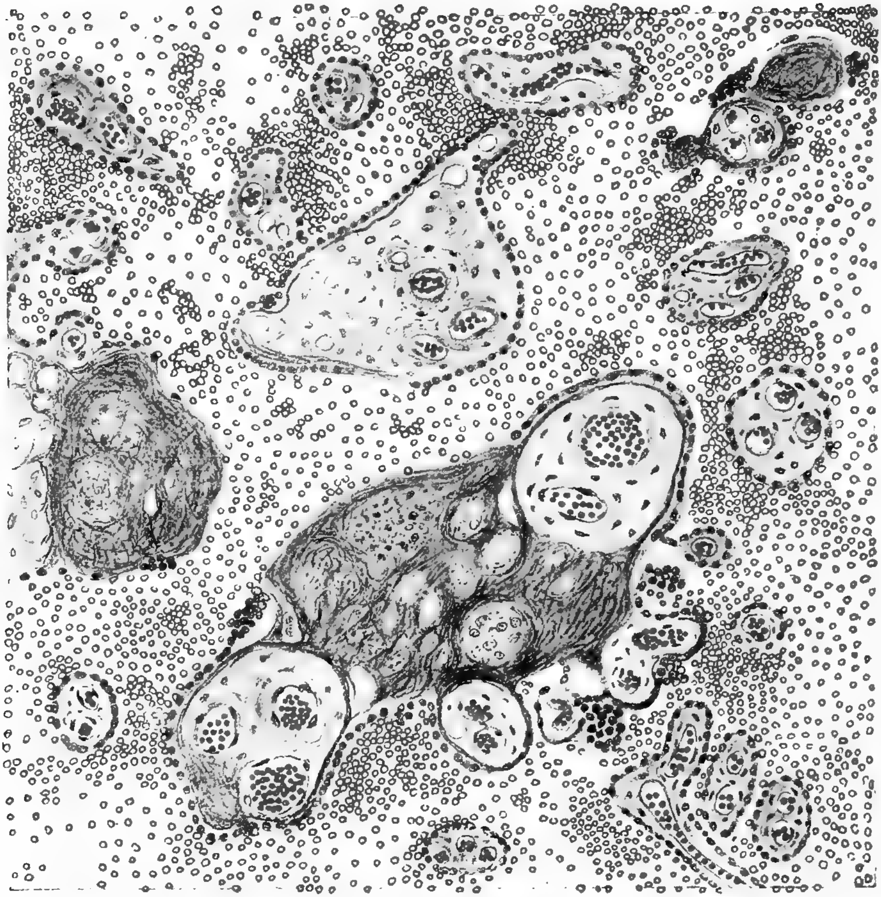


FIG. 575.—SECTION OF A PLACENTA AT FULL TIME. (T. H. Bryce.) From preparation by J. H. Teacher.

One or two of the villi show fibrinous degeneration. For the sake of distinction the fœtal blood-corpuscles are represented as solid dots, the maternal as circles.

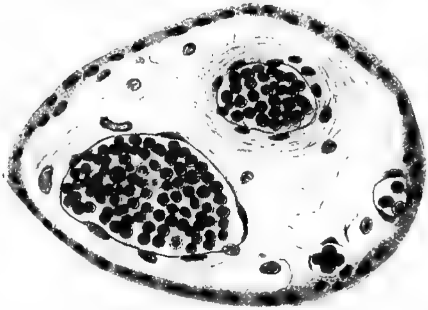


FIG. 576.—SECTION OF A VILLUS FROM A PLACENTA AT THE SEVENTH MONTH. Highly magnified. (T. H. Bryce.)

blends. As in the male sex, the wall of the urethra is formed of three coats, *mucous*, *submucous*, and *muscular*. The *mucous membrane* is lined throughout by stratified epithelium, except quite near the bladder where the epithelium is transitional. The *submucous coat* contains cavernous tissue, or at least a close plexus of veins. The *muscular coat* has two layers of plain muscle, an inner longitudinal and an outer circular;

there are also a few longitudinal striped fibres, chiefly confined to the anterior aspect of the tube.

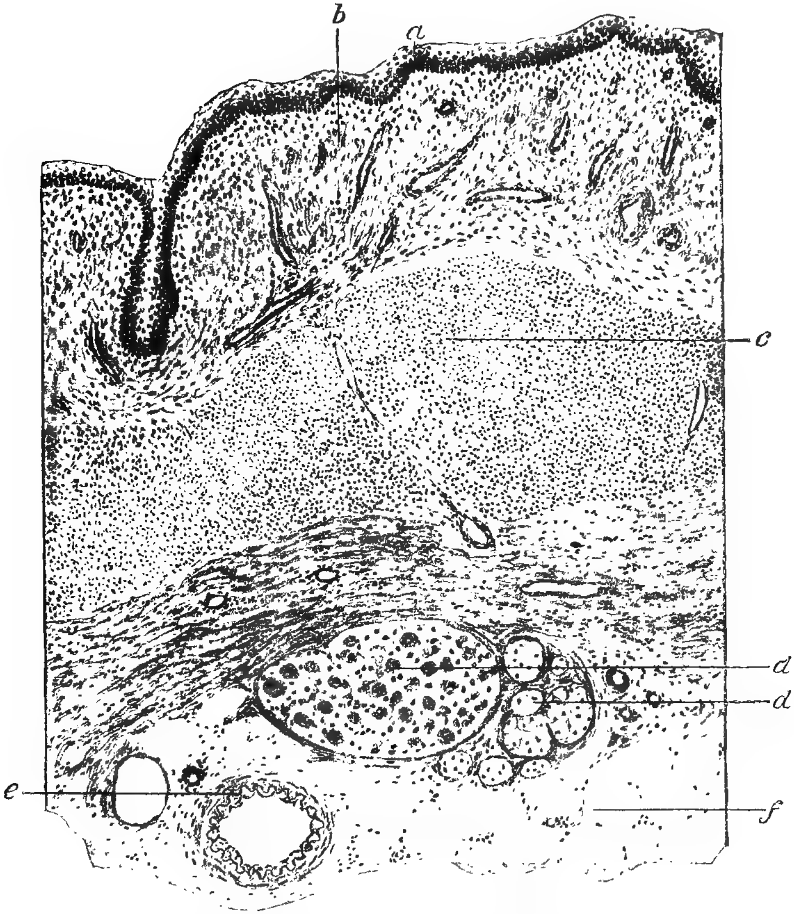


FIG. 577.—SECTION OF VAGINA OF MONKEY. (Marshall.)
a, stratified epithelium; *b*, corium of mucous membrane; *c*, muscular layer: the fibres cut across; *d*, a small ganglion; *d′*, nerve-bundles; *e*, a small artery; *f*, fat-cells

Numerous small acinous glands, similar to those of the prostate in the male, open on to the mucous membrane.

LESSON XXXIX.

THE SPINAL CORD.

1. SECTIONS of the spinal cord from the cervical, dorsal, and lumbar regions. If the human spinal cord cannot be obtained sufficiently fresh, that of a dog, cat, rabbit, or monkey may be used. It is to be hardened by suspending it immediately after removal from the body in a tall jar of formol (10 per cent. solution). After a few days it may be transferred to alcohol. Sections are to be made either by the paraffin or celloidin method: the former is preferable for small cords. The sections may be stained by Nissl's method, which brings to view the nerve-cells and also stains the axis-cylinders of the nerve-fibres. If it is desired to stain by the Weigert-Pal method, which colours the medullary sheaths of the nerve-fibres, the pieces of cord should be placed in 2 per cent. bichromate of potassium solution or Müller's fluid (either at once or after formol) and should be left for about a month, after which they are cut by a freezing microtome. (For the details of these methods see Appendix.) Carminate of ammonia or thionin may also be employed to stain the nerve-cells and axis-cylinders.

Notice the relative extent of the grey as compared with the white matter in the different regions of the cord.

Sketch a section from each region under a low power. Sketch also a small portion of the white substance, two or three nerve-cells, and the central canal with its lining epithelium and surrounding neuroglia under the high power.

Measure the diameter of some of the nerve-fibres in the ventral columns, in the lateral columns, and in the dorsal columns.

2. The development of the spinal cord may be studied in sections of chick embryos at various stages prepared by Golgi's method (see Appendix).

GENERAL STRUCTURE OF THE SPINAL CORD.

The **spinal cord** is composed of grey matter in the centre and of white matter externally. It is invested by three membranes, termed respectively *pia mater*, *arachnoid*, and *dura mater* (fig. 578). The pia mater is everywhere in close contact with the surface of the cord; by its means the blood-vessels are distributed to the organ. Next to the pia mater and separated from it by a considerable space, termed the subarachnoid space, is the arachnoid, a non-vascular membrane. In some parts the arachnoid lies close to the dura mater; in others it is separated from it also by a space containing fluid and known as the subdural space. The fluid in these spaces and in the corresponding spaces around the brain is known as cerebro-spinal fluid.

The arachnoid is a non-vascular areolar structure, resembling a serous membrane in general structure, but more delicate in texture. The dura mater, which immediately lines the vertebral canal, is a strong fibrous membrane. These membranes are continuous with the connective-tissue sheaths of the issuing spinal nerves.

At the middle of the ventral (anterior) and dorsal (posterior) surfaces the pia mater dips into the substance of the cord in the *ventral* and *dorsal median fissures*, so as to divide it almost completely into two lateral halves.

These are, however, united by an isthmus or bridge, which is composed ventrally of transversely crossing white fibres (*white commissure*), dorsally of grey matter (*grey commissure*), in the middle of which is a minute canal lined by ciliated epithelium (*central canal*).

Each lateral half of the spinal cord contains a crescent of grey matter, which is joined to the corresponding crescent of the opposite side by the grey commissure. Of the two horns of the crescent the dorsal is the narrower and comes near the surface of the cord : close to it the bundles of the dorsal nerve-roots enter the cord. The bundles of the ventral nerve-roots emerge from the corresponding horn.

According to Ingbert about 1,300,000 nerve-fibres enter the cord by the dorsal roots, and about one-third that number leave it by the ventral roots.

The dorsal root-fibres are derived from the cells of the spinal ganglia, which lie outside the cord ; the ventral root-fibres from cells within the grey matter, chiefly from cells in the ventral horn, but also from cells in the middle and dorsal parts of the grey matter and (especially in the thoracic region) from cells in the intermedio-lateral tract (lateral horn). The latter probably furnish the autonomic (sympathetic) fibres of the ventral roots, while the cells of the ventral horn furnish the fibres which are distributed to the voluntary muscles.

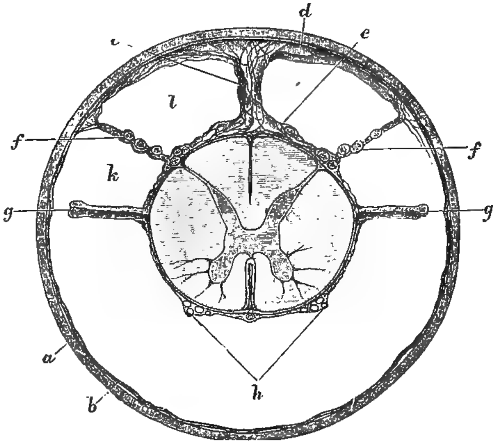


FIG. 578.—SECTION OF THE SPINAL CORD WITHIN ITS MEMBRANES. (Key and Retzius.)

a, dura mater ; *b*, arachnoid ; *c*, septum of arachnoid ; *d*, *e*, trabeculæ of arachnoid ; *g*, ligamentum denticulatum ; *f*, bundles of dorsal root ; *h*, bundles of ventral root ; *k*, *l*, subarachnoid space.

The *white matter* of each half of the cord is subdivided by the approach of the dorsal horn to the surface into two unequal columns —*ventro-lateral* and *dorsal*. A distinction is sometimes drawn between ventral and lateral portions of the ventro-lateral column, although there is no line of demarcation between them. In the upper part of the cord the dorsal column is subdivided by a septum of connective tissue into two—the *dorso-mesial column* or *funiculus gracilis*, and the *dorso-lateral column* or *funiculus cuneatus*.

The white matter is composed of longitudinally coursing, medullated nerve-fibres, which in sections stained with carmine or thionin appear as clear circular areas with a stained dot, the axis-cylinder, near the middle (fig. 580); while in sections stained by the Weigert-Pal method they appear as black circles with a clear centre. The nerve-fibres vary in size in different parts; on the whole those which are nearest to the surface of the cord are larger than those nearest to the grey matter, but there is a bundle of very small fibres opposite the tip of the posterior horn.

The medullated fibres are supported by *neuroglia*, which is composed of neuroglia cells and fibres (figs. 243 to 245). The neuroglia is accumulated in greater amount at the surface of the cord, underneath the pia mater (particularly, in the human cord, near the entrance of the dorsal roots (fig. 580)), and it extends into the grey matter, in which it is especially abundant in the *substantia gelatinosa* at the apex of the dorsal horn and around the central canal.

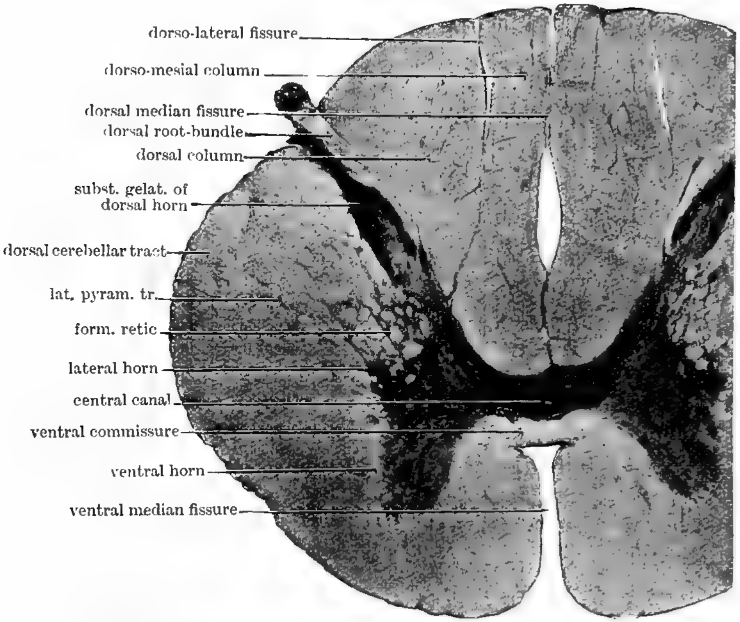


FIG. 579.—SECTION OF HUMAN SPINAL CORD FROM UPPER CERVICAL REGION. Photograph. Magnified about 8 diameters.

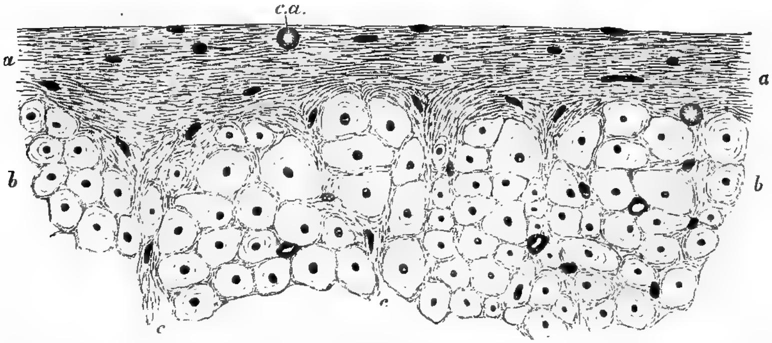


FIG. 580.—A SMALL PORTION OF A TRANSVERSE SECTION OF THE HUMAN SPINAL CORD IN THE REGION OF THE LATERAL COLUMN, TO SHOW THE SUPERFICIAL NEUROGLIA. Highly magnified.

a, *a*, superficial neuroglia; *b*, *b*, transverse section of part of the lateral column of the cord, in which the dark points are the axis-cylinders, and the clear areas the medullary substance of the nerve-fibres. The superficial neuroglia is seen to exhibit the appearance of a fine feltwork in which numerous nuclei and one or two *corpora amylacea*, *c.a.*, are embedded, and to extend inwards (*c*, *c*) among the nerve-fibres.

The *grey matter*, besides neuroglia, contains an interlacement of nerve-fibres and the arborisations of the dendrons of the nerve-cells which are embedded in it.

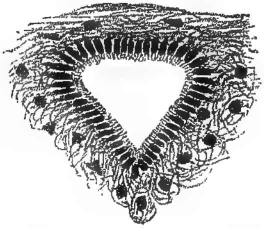


FIG. 581.—SECTION OF THE CENTRAL CANAL OF THE SPINAL CORD OF A CHILD, SHOWING ITS CILIATED EPITHELIUM AND THE SURROUNDING CENTRAL NEUROGLIA. Moderately magnified.

The **central canal** of the spinal cord is lined by columnar ciliated epithelium-cells (*ependyma*) which are surrounded by a quantity of neuroglia (figs. 581, 582, 583). The cells are best seen in the spinal cord of animals and in the child; in the human adult they have frequently become proliferated, and cilia are no longer present. In the early embryo their fixed extremities extend through the whole thickness of the cord to reach the pia mater. This condition is permanent in the cord of many of the lower vertebrata.

Blood-vessels of the spinal cord.—The blood-supply of the grey matter is derived mainly from a series of arterioles, which come off from the mesially situated ventral spinal artery, pass into the ventral median fissure, and

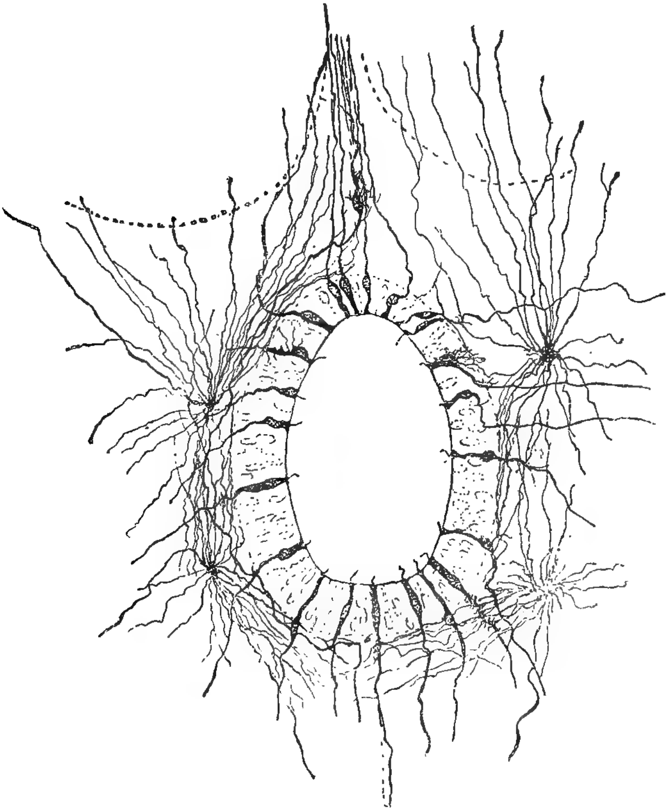


FIG. 582.—EPENDYMA AND NEUROGLIA-CELLS AROUND CENTRAL CANAL OF CORD. (Lenhossék.) Golgi method.

at the bottom of this divide each into two branches, one for the grey matter of each lateral half of the cord. In the grey matter is a very close capillary plexus which is supplied not alone by the vessels just mentioned, but also by small arterioles which converge from the small arteries of the pia mater, passing through the white matter, and supplying this as they traverse it. These arterioles are branches of the above-mentioned ventral spinal artery and of the dorsal spinal arteries (which run on each side along the line of the dorsal roots). The capillary plexus of the white matter is far less dense than that of the grey matter. It forms longitudinal meshes.

The veins of the spinal cord accompany the arteries. Two longitudinal venous vessels, accompanying corresponding anastomotic arterioles, are seen, one on either side of the central canal, in most transverse sections of the cord.

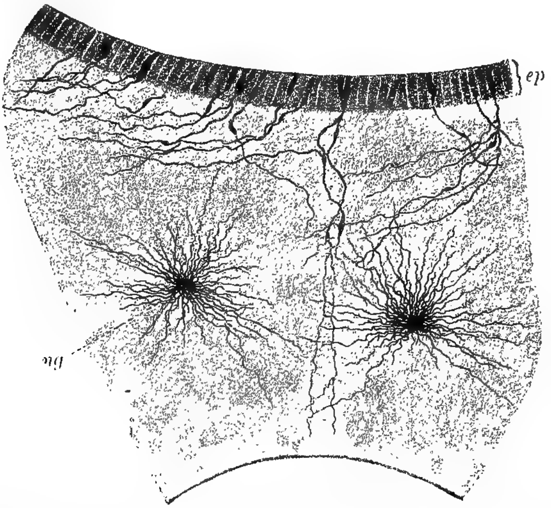


FIG. 583.—PART OF EPITHELIUM OF CENTRAL CANAL OF NEW-BORN CHILD, STAINED BY GOLGI'S METHOD. (Sobotta.) Magnified 120 diameters.

ep, epithelium; *ng*, neuroglia-cells in adjacent grey matter.

CHARACTERS OF THE SPINAL CORD IN ITS SEVERAL REGIONS.

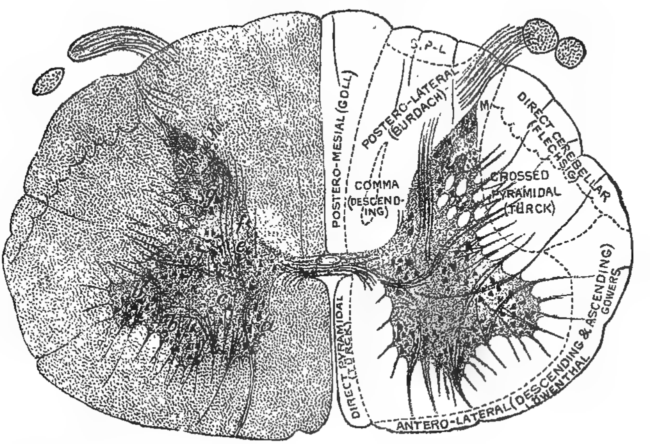
In the *cervical region* (fig. 584, A), the white matter, especially that of the lateral columns, occurs in largest proportion. The grey matter in the cervical enlargement is also in considerable amount, and it encroaches, especially in the upper part of the region, in the form of a network (*formatio reticularis*) upon the adjacent part of the lateral white column (fig. 579). The ventral horns are thick and the dorsal slender. The dorso-mesial column is distinctly marked off.

In the *thoracic region* (B) the grey matter is small in amount, and both horns are slender. The whole cord is smaller in diameter than either in the cervical or lumbar region. The columns of nerve-cells known as Clarke's column and the intermedio-lateral column are well marked.

In the *lumbar region* (C) the crescents of grey matter are very thick, and the white substance, especially the lateral columns, relatively small in amount. The isthmus lies nearly in the centre of the cord, whereas in the cervical and dorsal regions it is nearer the ventral surface.

In the part of the spinal cord from which the *sacral* and *coccygeal* nerve-roots take origin grey matter largely preponderates, the crescents form thick irregular masses, and the grey isthmus is also of considerable thickness.

A


S.P.-L
POSTERO-MESIAL (GOLL)
POSTERO-LATERAL (BURDACH)
COMMA (DESCENDING)
M
DIRECT CEREBELLAR (FLECHSIG)
CROSSED PYRAMIDAL (TÜRCK)
(DESCENDING & ASCENDING) GOWERS
DIRECT PYRAMIDAL (TÜRCK)
ANTERO-LATERAL (DESCENDING LOWENTHAL
g
f
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c
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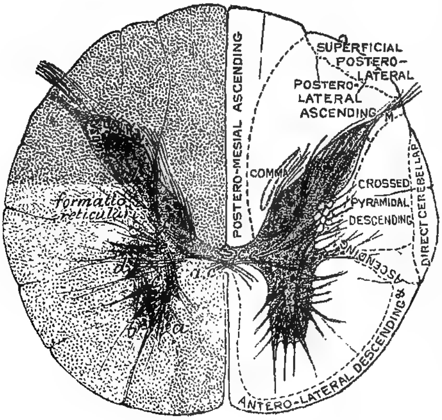
B


POSTERO-MESIAL ASCENDING
SUPERFICIAL POSTERO-LATERAL
POSTERO-LATERAL ASCENDING
M
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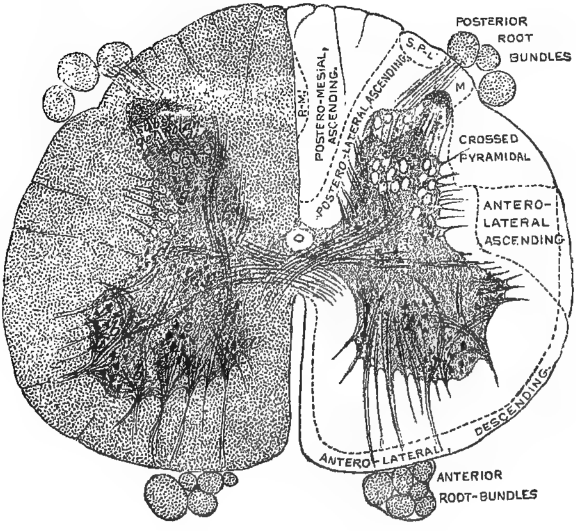
CROSSED PYRAMIDAL DESCENDING
DIRECT CEREBELLAR
ASCENDING
ANTERO-LATERAL DESCENDING &
formatio reticularis
d
a.c
b
a

FIG. 584.—SECTIONS OF HUMAN SPINAL CORD FROM THE LOWER CERVICAL (A), MID-THORACIC (B), AND MID LUMBAR (C) REGIONS, SHOWING THE PRINCIPAL GROUPS OF NERVE-CELLS, AND ON THE RIGHT SIDE OF EACH SECTION THE CONDUCTING TRACTS AS THEY OCCUR IN THE SEVERAL REGIONS.

a, *b*, *c*, groups of cells of the ventral or anterior horn; *d*, cells of the lateral horn; *e*, middle group of cells; *f*, cells of Clarke's column; *g*, cells of dorsal or posterior horn; *c.c*, central canal; *a.c*, ventral commissure; M, marginal bundle of Lissauer; P.M'., septomarginal tract.

C



LESSON XL.

THE SPINAL CORD (*continued*).

1. TRACTS in the spinal cord. The conducting tracts of the spinal cord may be studied in two ways, viz.: (1) by preparing sections of embryonic cords (from the 5th to the 9th month), the sections being stained by the Weigert-Pal process; (2) by preparing sections from the cord of an animal in which semi-section has been performed about 15 days before the animal is killed. The cord must first be partly hardened by placing it for a few days in Müller's fluid. Thin pieces taken from below and from above the level of the section are then placed in a solution consisting of two parts of Müller's fluid and 1 part of 1 per cent. osmic acid (Marchi's method, see Appendix).

2. Grouping of cells in the cord. These are studied in sections stained by Nissl's method (see Appendix).

TRACTS OF NERVE-FIBRES IN THE WHITE COLUMNS.

The course of the nerve-tracts in the spinal cord, and in other parts of the central nervous system, can be made out by the method of Flechsig, which involves the study of sections of the developing cord; for it is found that the formation of medullary substance occurs sooner in some tracts than in others, so that it is easy to make out the distinction between them. Thus, the peripheral nerves and nerve-roots become myelinated in the first half of the fifth month of fœtal life. Of the tracts of the spinal cord, those of Burdach and Goll (see below) are the first to be myelinated, then the tracts of Flechsig and Gowers, all of these being afferent or centripetally conducting, while the pyramid-tracts, which are efferent or centrifugally conducting, do not receive their myelin sheath until after birth.[1]

Another method (that of A. Waller, p. 174) consists in investigating the course which is pursued by degeneration of the nerve-fibres in consequence of lesions produced accidentally or purposely. Those tracts in which degeneration of fibres occurs below the lesion are termed "descending" tracts; those in which it occurs above the lesion are termed "ascending." This method, when combined with the staining process devised by Marchi, is by far the more valuable, since it enables even single fibres to be traced far from their source.

Further, the cells whence the fibres of any tract arise can be identified, after a lesion of the tract, by the chromatolysis or degeneration of Nissl, which nerve-cells undergo after section of their axons (see pp. 175, 176).

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[1] Flechsig finds that the fibres of the dorsal roots are myelinated in at least three stages, and that the dorso-lateral tract shows a corresponding differentiation into three chief parts: the *ventral, middle, and dorsal root-zones.* He suggests that this differentiation corresponds with functional differences of the fibres.

Tracts of the dorsal column.—1. *Tract of Goll.*—Most of the fibres of the *dorso-mesial column* belong to a tract which is known as the *tract of Goll* (fig. 588, 6). This consists of fibres derived from the dorsal nerve-roots of the sacral, lumbar, and lower thoracic nerves, which, after having entered the dorso-lateral columns, shift, as they ascend, towards the dorsal median fissure and form a distinct tract, which is marked off from the rest of the dorsal column in the cervical region by a slight furrow and a septum of pia mater (fig. 579). This tract ends amongst the cells of the *nucleus gracilis* of the medulla oblongata.

2. *Tract of Burdach.*—The *dorso-lateral column* is also mainly composed of fibres of the dorsal nerve-roots, which run for a certain distance in it before entering the grey matter of the cord or of the medulla oblongata. As each mass of dorsal root-bundles enters the column close to the apex of the horn it, so to speak, pushes the root-fibres which have already entered nearer to the median fissure; hence those which are derived from the lowest nerve-roots are nearest that fissure (tract of Goll), while those which are derived from the highest remain near the horn (tract of Burdach) (figs. 585 to 587). Many of the fibres of both tracts pass into the grey matter either immediately on entering the cord or in their course upwards;

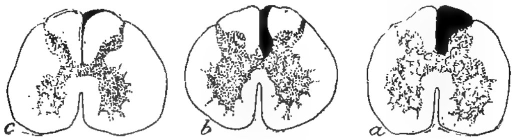

FIG. 585.—DIAGRAM SHOWING THE SITE OF DEGENERATION IN THE DORSAL COLUMN WHICH RESULTS FROM UNILATERAL SECTION OF THE DORSAL ROOTS OF THE SECOND SACRAL TO THE SIXTH LUMBAR NERVES OF THE DOG. (Singer.)

a, sixth lumbar segment; *b*, fourth lumbar; *c*, from the mid-thoracic region.

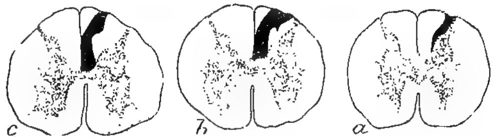

FIG. 586.—DEGENERATIONS FOLLOWING UNILATERAL SECTION OF THE DORSAL ROOTS OF THE ELEVENTH AND TWELFTH THORACIC NERVES OF THE DOG. (Singer.)

a, at level of twelfth thoracic; *b*, of third thoracic; *c*, from mid-cervical region.

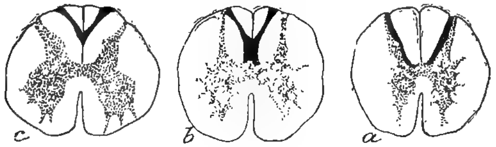

FIG. 587.—DEGENERATIONS FOLLOWING BILATERAL SECTIONS OF THE DORSAL ROOTS OF THE SECOND THORACIC TO FIFTH CERVICAL NERVES OF THE DOG. (Kahler.)

a, at level of first thoracic; *b*, at sixth cervical; *c*, at first cervical.

the rest are continued into the medulla oblongata, and those of the tract of Burdach end by arborising amongst the cells of the *nucleus cuneatus*.

3. *Comma tract.*—Besides the tracts of Burdach and Goll, which are wholly composed of long "ascending" fibres having their cells of origin in the ganglia on the dorsal roots, there are a few fibres which have a shorter "descending" course in the dorsal columns. These are thought by some authors to arise from descending branches of the dorsal root-fibres, by others from cells in the grey matter of the cord. They form the so-called *comma tract* (fig. 588, 5).

Proprio-spinal or endogenous fibres of the dorsal column.—These comprise a few fibres (*septo-marginal*), chiefly accumulated near the median fissure (*oval bundle*) and near the dorsal surface (*median triangle bundle*), as well as others scattered in the column; they are derived from cells in the grey matter of the cord itself, and all take a "descending" course in the dorsal column.

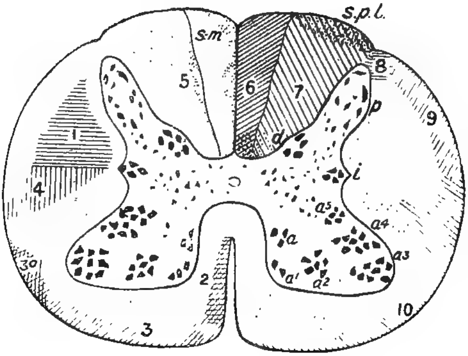

FIG. 588.—DIAGRAM SHOWING THE ASCENDING (RIGHT SIDE) AND DESCENDING (LEFT SIDE) TRACTS IN THE SPINAL CORD.

1, Crossed pyramid tract; 2, direct pyramid tract; 3, ventro-lateral descending; 3*a*, bundle of Helweg; 4, prepyramidal; 5, comma; 6, dorso-mesial; 7, dorso-lateral; 8, tract of Lissauer; 9, dorsal cerebellar; 10, ventro-lateral ascending or ventral cerebellar; *s-m*, septo-marginal; *s.p.l.*, superficial dorso-lateral fibres (dorsal root-zone of Flechsig); *a* to a^5, groups of cells in the ventral horn; *i*, intermedio-lateral group or cell-column in the lateral part of the grey matter; *p*, cells of dorsal horn; *d*, dorsal nucleus of Stilling or cell-column of Clarke. The scattered dots indicate the situation of "endogenous" fibres (arising in grey matter of cord) having for the most part a short course. There are many more of these fibres, near the grey matter, not indicated in the diagram.

There are, however, other fibres which arise in the grey matter and having an "ascending" course are especially numerous in the ventral part of the column.

Tracts of the ventro-lateral column: descending tracts.—1. *Pyramid tract or cortico-spinal tract.*—At the dorsal part of the lateral column there is a tract of moderately large "descending" fibres which are found to run in the lateral column of the spinal cord from the opposite side of the brain, after having for the most part crossed at the decussation of the pyramids of the medulla oblongata (*crossed lateral pyramid tract*, fig. 588, 1; fig. 589, 1*a*). Intermingled with the fibres of the crossed pyramid tract in the lateral column are a few fibres of the pyramid which have not crossed in the medulla oblongata, and which are therefore derived from the cerebral cortex of the same side (*uncrossed lateral pyramid fibres*, fig. 589, 1*b*). Certain large fibres which lie in the ventral column next to the median fissure in the human subject, also belong to a portion of the same tract which has not undergone decussation (*direct pyramid tract*, figs. 588, 589, 2). The direct pyramid

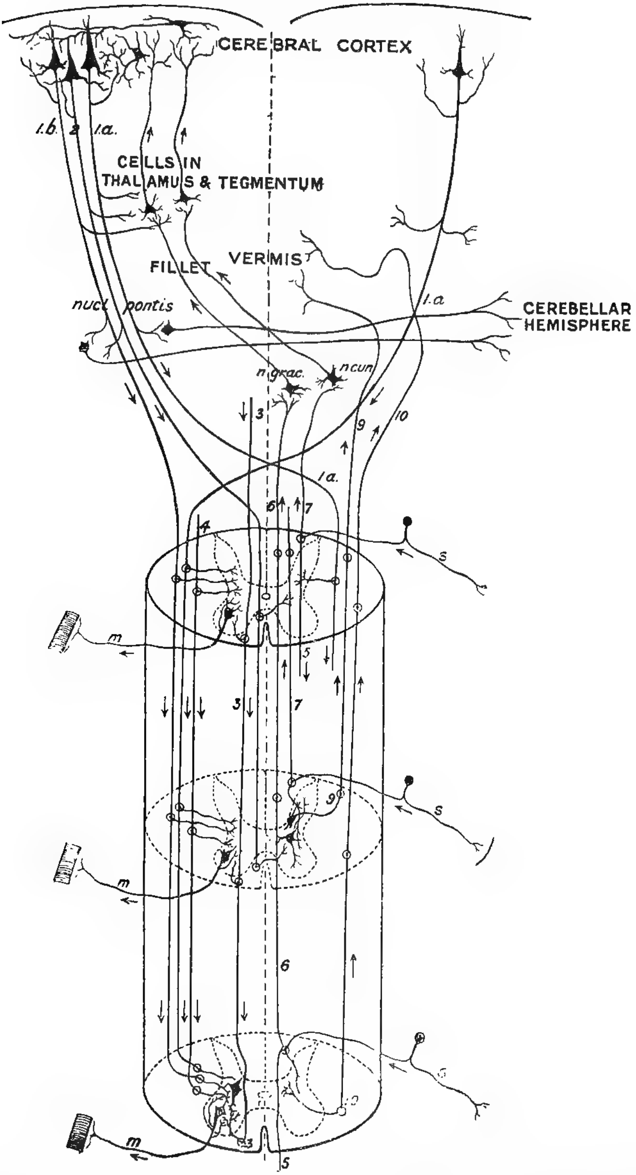

FIG. 589. DIAGRAM SHOWING THE COURSE, ORIGIN, AND TERMINATION OF THE FIBRES OF THE PRINCIPAL TRACTS OF THE WHITE MATTER OF THE SPINAL CORD. (The numbers in this diagram refer to fibres of the tracts shown with corresponding numbers in fig. 588.)

"Descending" tracts:—*1a*, a fibre of the crossed pyramid tract; *1b*, an uncrossed fibre of the pyramid tract passing to the lateral column of the same side; *2*, a fibre of the direct pyramid tract; *3*, a fibre of the ventro-lateral descending tract; *4*, a fibre of the prepyramidal tract; *5*, fibres of the comma tract. "Ascending" tracts:—*6*, a fibre of the dorso-mesial tract; *7*, fibres of the dorso-lateral tract; *9*, one belonging to the dorsal cerebellar; *10*, a fibre of the ascending ventro-lateral or ventral cerebellar tract. Also, *m*, motor nerves; *s*, sensory (afferent) nerves; *n.grac.*, nucleus gracilis; *n.cun.*, nucleus cuneatus; *nucl. pontis*, nucleus of pons. The arrows indicate the direction of the nerve-impulses.

tract is only found in man and the anthropoid apes; it varies considerably in extent. It is always most distinct in the cervical region, becoming gradually lost as it is traced down.

The pyramid tracts are composed of "descending" fibres, which have their cells of origin in the cerebral cortex (precentral and paracentral gyri) and end by arborisations in the grey matter at the base of the dorsal horn of the spinal cord. In some mammals (rat, mouse, guinea-pig, sheep, kangaroo, squirrel, etc.) the pyramid tracts are situated in the dorsal columns of the cord, in others, including the monkey, dog, cat, and rabbit, they run wholly in the lateral columns. The pyramid tracts are very small in the lower mammals, and are not found at all in vertebrates below mammals.

It has been calculated that there are about 80,000 fibres of the pyramid tract in each half of the human cord. The pyramid tracts are generally regarded as the paths along which volitional impulses are conveyed from the cerebral cortex to the spinal cord. But experiments have shown that they are not the only cortico-spinal paths nor even the most important in many mammals, for the paralysis which results from their section is soon recovered from in most mammals, whereas that resulting from section of the ventral column and adjacent part of the lateral column may be marked and permanent in animals, although such section in man may produce no motor paralysis. It appears to be the finer and more delicate movements which are permanently lost when the pyramid tract is affected by disease in man.

2. *Tract of Loewenthal.*—Besides the pyramid tracts there are four other "descending" tracts of fibres in the ventro-lateral column. One of these (the *ventro-lateral descending tract* or *tract of Loewenthal*, figs. 588, 589, 3) lies on the side of the ventral median fissure, and extends along the margin of the cord in the "root" zone, even reaching the ventral part of the lateral column. These fibres are continued down, chiefly from the *dorsal longitudinal bundle* of the medulla oblongata and pons (*bulbo-spinal and ponto-spinal fibres*), partly from other sources which will be afterwards referred to. They end by arborisations in the ventral horn. Similar arborisations pass from the dorsal longitudinal bundle to the nuclei of the motor cranial nerves. This tract is mainly uncrossed.

3. *Rubro-spinal tract.*—Another "descending" tract in the ventro-lateral column lies just in front of the crossed pyramid tract; this is the *pre-pyramidal or rubro-spinal tract* (figs. 588, 589, 4). Its fibres end by arborising in the grey matter of the middle of the crescent; the situation of its cells of origin is the red nucleus of the tegmentum in the mid-brain (p. 462). This tract is also known as *Monakow's tract.* Some of its fibres may be derived from cells in the reticular formation of the pons and medulla oblongata.

4. *Tecto-spinal fibres.*—Intermingled with the fibres of the rubro-spinal tract (but far fewer in number in man) are fibres derived from the quadrigeminal bodies of the opposite side. These fibres form a part of the *tecto-spinal tract.* Another part of this tract (*ventral longitudinal bundle*) passes

down the ventral column of the cord along with the fibres of the tract of Loewenthal.

5. *Olivo-spinal tract.*—This is a small triangular group of "descending" fibres traceable from the neighbourhood of the olive in the medulla oblongata, and passing down the cervical cord in the ventral part of the

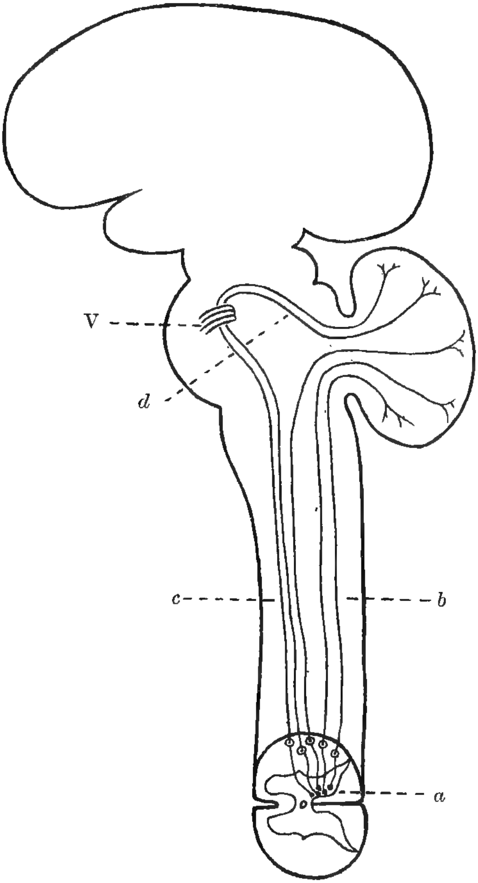

FIG. 590.—DIAGRAM SHOWING THE COURSE OF THE SPINO-CEREBELLAR FIBRES CONSTITUTING THE TRACTS OF FLECHSIG AND OF GOWERS IN THE SPINAL CORD AND THEIR CONTINUATIONS TO THE CEREBELLUM.

a, cells of Clarke's column in the dorsal horn of the spinal cord, giving origin to fibres which pass into both spino-cerebellar tracts; *b*, tract of Flechsig, passing above by way of the restiform body to the cerebellar vermis; *c*, tract of Gowers; *d*, passage of most of its fibres along the superior peduncle to the vermis of the cerebellum: they are seen turning sharply backwards immediately after passing the level of the place of exit of the 5th nerve (V). Some of the fibres of this tract leave it in the medulla oblongata and join the fibres of the tract of Flechsig which are passing to the cerebellum by its inferior peduncle. One such fibre is shown in the diagram.

lateral column (fig. 518, 3*a*); the exact origin and destination of its fibres is unknown. It is also known as the *bundle of Helweg*.

Ascending tracts of the ventro-lateral column.—1. *Tract of Flechsig.*—This is a well-marked tract, which is, however, only distinct in the cervical and dorsal regions, where it lies external to the crossed pyramid tract. It consists of large fibres which are derived from the cells of Clarke's column (fig. 588, *d*) and which pass into the lower or posterior part of the cerebellar vermis by the inferior peduncle of the same side (*dorsal spino-cerebellar tract; direct cerebellar tract*, fig. 584; also figs. 588, 589, 9; 590, *b*).

2. *Tract of Gowers, ventro-lateral ascending tract.*—This is situated ventrally to the tract of Flechsig and the lateral crossed pyramid tract in the lumbar region; while in the thoracic and cervical regions it forms a narrow band of fibres curving round close to the lateral surface of the cord, and extending into the ventral column (figs. 588, 589, 10). Its fibres are partly intermingled with those of the ventro-lateral descending tract. Most of the fibres of the tract of Gowers are connected with the upper or anterior part of the vermis of the cerebellum. They constitute the *ventral spino-cerebellar tract*, which passes to the cerebellum along with the superior cerebellar peduncle (fig. 590). Both in the cord and medulla oblongata it gives off fibres to join the tract of Flechsig and to pass in this to the cerebellum by the inferior peduncle. According to Van Gehuchten, confirmed by Collier and Buzzard, the tract of Gowers gives off a few fibres to enter the opposite cerebellar hemisphere by the middle peduncle.

Some of the fibres included within the area of Gowers' tract are continued up to the corpora quadrigemina (*spino-tectal tract*). Others pass into the tegmentum of the crus cerebri, where they can be traced as far as the lower part of the thalamus (*spino-thalamic tract*).

The fibres of Gowers' tract take origin from the cells of Clarke's column, of the same side of the cord, especially from its lower part. This is the case at least with the cerebellar fibres. But the tectal and thalamic fibres probably arise from cells situated in the middle and dorsal parts of the grey matter, partly on the same but chiefly on the opposite side of the cord.

3. *Tract of Lissauer.*—Lastly, there is another small tract of fibres which undergoes degeneration above the point of section of the cord. This is the *marginal bundle* of Lissauer (marked M in fig. 584). It is formed by fine fibres from the posterior roots. Many of these fibres are non-medullated. They are said to be derived from the small, darkly staining cells of the spinal ganglia (p. 171).

Other portions of the ventro-lateral columns near the grey matter which are differentiated by the method of Flechsig are probably short tracts uniting adjacent portions of the grey matter of the cord.

Proprio-spinal or endogenous fibres of the ventro-lateral column.—Sherrington has shown that in the dog the lateral column in the thoracic region of the cord contains a certain number of long fibres which take origin in the cervical, thoracic and upper lumbar segments and are traceable down to the lumbo-sacral enlargement. These must serve to convey excito-reflex impulses from the upper to the lower parts of the body. Probably similar

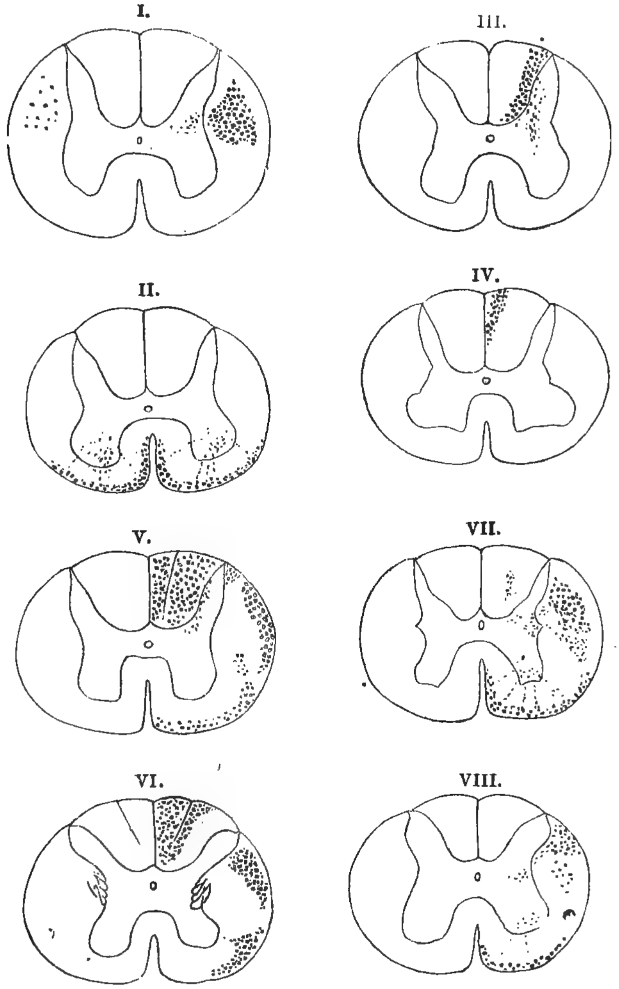

FIG. 591.—DIAGRAM OF SECTIONS OF THE SPINAL CORD OF THE MONKEY SHOWING THE POSITION OF DEGENERATED TRACTS OF NERVE-FIBRES AFTER SPECIFIC LESIONS OF THE CORD ITSELF, OR OF AFFERENT NERVE-ROOTS OR OF THE MOTOR REGION OF THE CEREBRAL CORTEX. The degenerations are shown by the method of Marchi. The left side of the cord is at the reader's left hand.

I. Degenerations resulting from extirpation of the motor area of the cortex of the left cerebral hemisphere. In man there would be some degenerated fibres in the left ventral column also, close to the ventral fissure.

II. Degenerations produced by section of the dorsal longitudinal bundles in the upper part of the medulla oblongata.

III. and IV. Result of section of dorsal roots of the first, second, and third lumbar nerves on the right side. Section III. is from the segment of cord between the last thoracic and first lumbar roots; Section IV. from the same cord in the cervical region.

V. to VIII. Degenerations resulting from (right) lateral section of the cord in the upper thoracic region. V. is taken a short distance above the level of section; VI., higher up the cord (cervical region); VII., a little below the level of section; VIII., lumbar region.

fibres arise all along the cord from the cells of the lateral column and pass upwards as well as downwards.

A tract of endogenous fibres has been observed in man close to the ventral median fissure lying amongst the fibres of the direct pyramid tract. This is known as the *ventral sulco-marginal tract* of Marie.

The ventro-lateral column contains also many endogenous fibres, both ascending and descending, derived from cells in the grey matter of the cord, which have only a short course, serving to connect adjacent segments.

GROUPS OF CELLS IN GREY MATTER OF CORD.

The nerve-cells which are scattered through the grey matter are in part disposed in definite groups. Thus there are several groups of large multipolar nerve-cells in the ventral horn in the cervical and lumbar enlargements (fig. 584), although in other regions of the cord the number of groups in this situation is reduced to two, a mesial and a lateral. The larger groups in the enlargements correspond with segments of the limb (Van Gehuchten); thus there appear to be groups associated with foot, leg, and thigh, and with hand, arm, and shoulder movements respectively. The groups from which the motor nerves to the shoulder and arm muscles arise, appear in somewhat higher segments of the cervical cord than those belonging to the hand muscles. The same holds good, *mutatis mutandis*, for the lumbar cord in relation to the leg and foot. Further, the larger groups show subdivisions which may be related to particular movements, *i.e.*, to particular groups of muscles. In the case of the diaphragm there is a special cell-group or cell-column in the ventral horn of the cervical cord from which the fibres of the phrenic nerve arise, so that in this case a cell-group is set apart for a special muscle.

The axis-cylinder processes of the ventral horn cells mostly pass out into the corresponding ventral nerve-roots (fig. 589, *m*), but a few send their axons to the ventral column of the opposite side through the white commissure or to the ventral or lateral column of the same side. It is noteworthy that in birds a few cells of the ventral horn send their axons into the dorsal roots. A well-marked group of large nerve-cells, best marked in the thoracic region, lies at the base of the dorsal horn (*dorsal nucleus of Stilling*, *Clarke's column*, fig. 588, *d*). The cells of Clarke's column send their axis-cylinder processes into the dorsal cerebellar tract (Mott). If this tract be cut experimentally, the large cells of Clarke's column on the same side below the section undergo Nissl degeneration and eventually atrophy, but the degeneration does not affect all these cells unless the tract of Gowers be also severed (Ninian Bruce). There are in addition a few small cells with short axons in Clarke's column which do not give rise to fibres of either of these long tracts.

Another group is seen on the outer side of the grey matter lying in a projection which is sometimes known as the *lateral horn* (*lateral cell-column*, *intermedio-lateral column*, fig. 588, *i*). This is most distinct in the thoracic region as far up as the second thoracic segment. The axons from its cells for the most part leave the cord along with the ventral roots, and probably

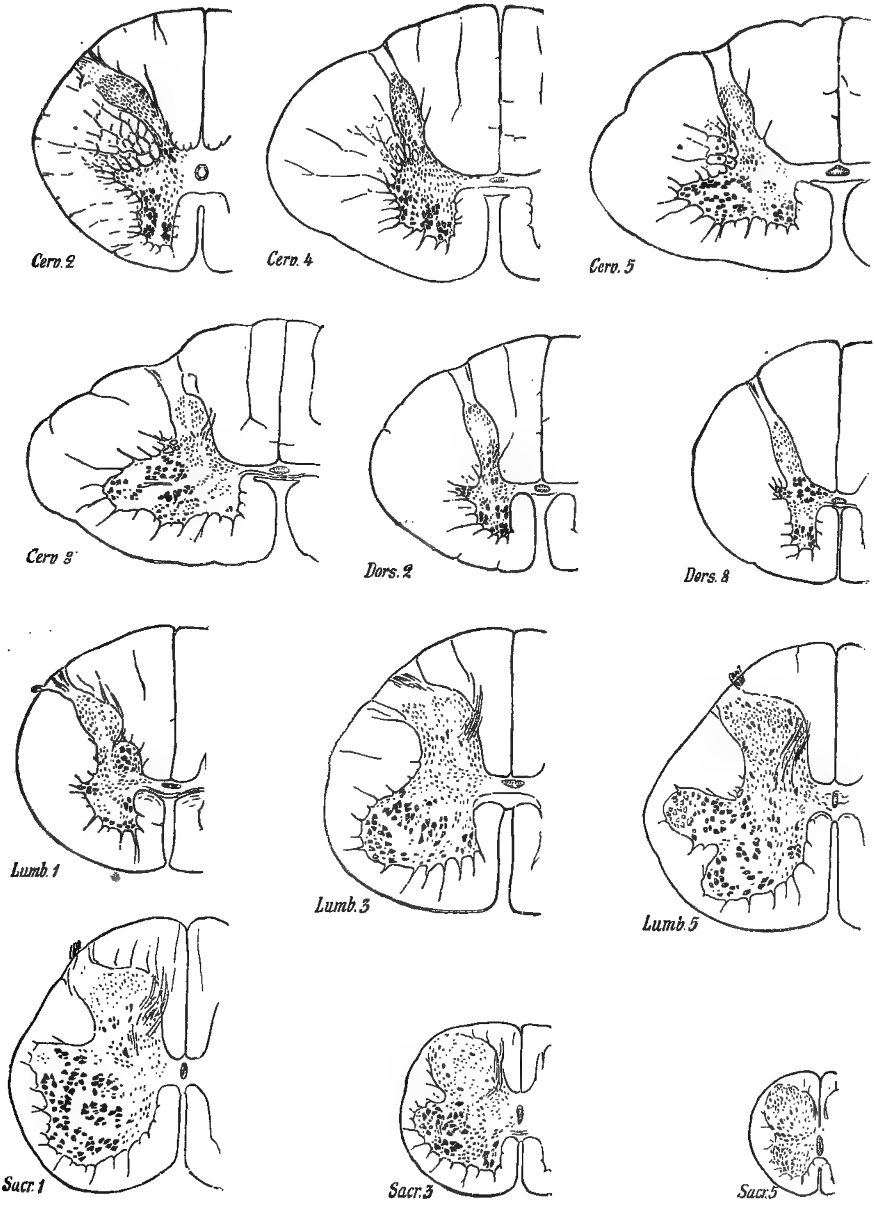

FIG. 592.—DIAGRAM OF SECTIONS OF HUMAN SPINAL CORD AT DIFFERENT LEVELS. (Edinger.)

The names refer to the origin of the corresponding nerve-roots. The relative shape and size of the cord and grey matter, the relative amounts of grey and white matter, and the size and position of the principal cell-groups are shown.

furnish the outgoing visceral and vascular fibres (preganglionic sympathetic fibres of Langley). Another group (*middle cell-column*) lies in the middle of the crescent (fig. 584, *e*). Cells are very numerous in the dorsal horn but are not collected into definite groups. Those of the substantia gelatinosa of Rolando send their nerve-fibre processes partly into the lateral, partly into the dorsal columns.

The cells which send their axons into the adjacent parts of the white columns but not into any special tract are sometimes termed the "cells of the white columns."

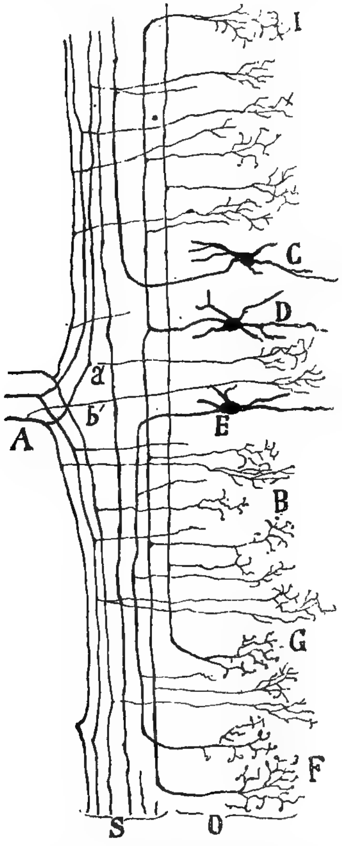

Fig. 593.—From longitudinal section of cord of chick embryo, showing entering dorsal root-fibres and the passage of collaterals from them into the grey matter. Also three cells of the dorsal horn sending their axons into the white matter. (Cajal.)

A, entering root-fibres; S, dorsal white column; O, grey matter; C, D, E, cells of dorsal horn; B, F, G, I, arborisation of collaterals in grey matter.

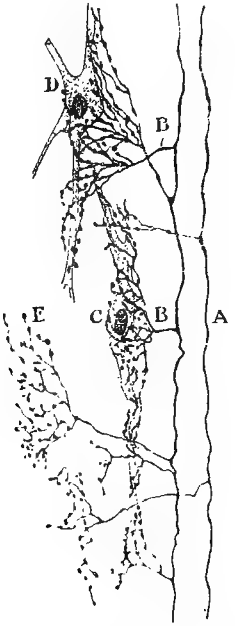

Fig. 594.—Arborisation of collaterals from the dorsal root-fibres around cells of the dorsal horn of grey matter. (Cajal.)

A, fibres of dorsal column derived from dorsal root; B, collaterals; C, D, nerve-cells in grey matter surrounded by the arborisations of the collaterals; *E*, an arborisation shown separately.

CONNEXION OF THE NERVE-ROOTS WITH THE SPINAL CORD.

The *ventral* (*anterior*) *roots* leave the ventral horn in a number of bundles. Most of their fibres are directly continued from the nerve-cells in the ventral and lateral horns; according to Golgi in part also from cells in the dorsal horn. The cells, from which the ventral root-fibres arise, are surrounded by an interlacement of ramified nerve-endings, which are derived from various sources, especially from axons of cells of the dorsal horn, from collaterals of the dorsal root-fibres (see below), and from those of the fibres of the adjacent white columns.

The fibres of the *dorsal (posterior) roots* originate in the cells of the root ganglia and enter the dorso-lateral column (see diagram, fig. 589), but the smallest fibres pass to the marginal bundle of Lissauer, and some go directly into the dorsal horn. On entering the spinal cord the fibres bifurcate (fig. 593), one branch passing upwards, the other downwards. Both from the main fibre and from its branches collateral fibres pass at frequent intervals into the grey matter, and end in arborisations of fibrils which envelop the nerve-cells both of the dorsal (fig. 594) and of the ventral horn (fig. 595), and, in the thoracic region, the cells of Clarke's column and those of the intermedio-lateral column. Many of the main fibres also ultimately end in a similar manner in the grey matter, some after a short course only, others after a long course. But a considerable number of fibres pass upwards in the dorso-lateral and dorso-mesial columns (in the latter especially those of the lower spinal nerves), until they arrive at the medulla oblongata, where they end in terminal arborisations around the cells of the nucleus gracilis and nucleus cuneatus (fig. 589, 6, 7).

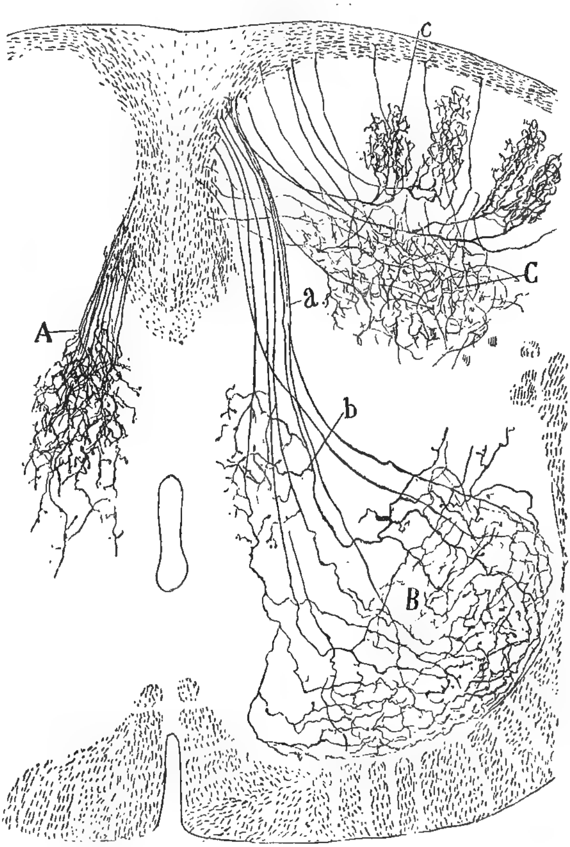

FIG. 595.—COLLATERALS FROM THE DORSAL COLUMN FIBRES PASSING INTO THE GREY MATTER: NEW-BORN MOUSE. (Cajal.) Golgi method.

A, a bunch of collaterals ending amongst the cells of the middle cell column; B, ending of collaterals, *a*, in the ventral horn: a few side branches of these collaterals, *b*, are passing to the middle cell column; C, collaterals to dorsal horn; *c*, others to substance of Rolando.

LESSON XLI.

THE MEDULLA OBLONGATA.

SECTIONS of the medulla oblongata (made in the same way as with the spinal cord): (*a*) at the level of the decussation of the pyramids, (*b*) just above the decussation, (*c*) opposite the middle of the olivary body, and (*d*) either through the uppermost part of the olivary body, or just above it.

The brain consists of three great morphological divisions associated with the three primary cerebral vesicles of the embryo; they are termed respectively the *hind-brain*, *mid-brain*, and *fore-brain.*

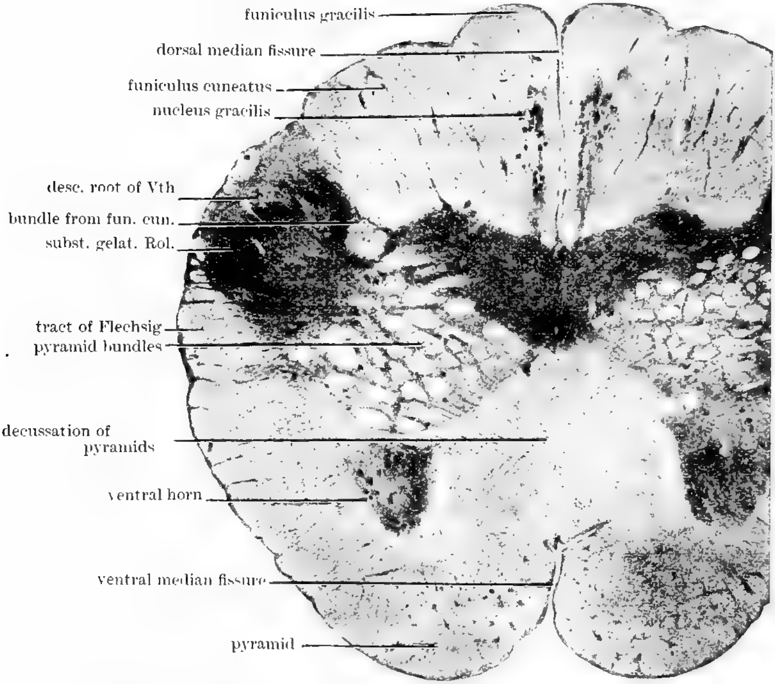

FIG. 596.—SECTION ACROSS THE LOWER PART OF THE MEDULLA OBLONGATA IN THE REGION OF THE DECUSSATION OF THE PYRAMIDS. Magnified 6½ diameters.

The **hind-brain** includes the parts around the fourth ventricle, viz. the medulla oblongata (myelencephalon), and the pons Varolii with the cerebellum (metencephalon): the medulla oblongata and pons form a continuation of the spinal cord and may be termed the *spinal bulb.* The **mid-brain** includes the region of the corpora quadrigemina (mesencephalon). The **fore-brain** comprises the parts immediately above that region and centring around the third ventricle; its lower portion includes the optic thalami (thalamencephalon), its upper portion the corpora striata and cerebral hemispheres (telencephalon).

The structure of the **medulla oblongata** can best be made out by the study of a series of sections taken from below upwards, and by tracing in these the changes which occur in the constituent parts of the spinal cord, taking note at the same time of any parts which may be superadded.

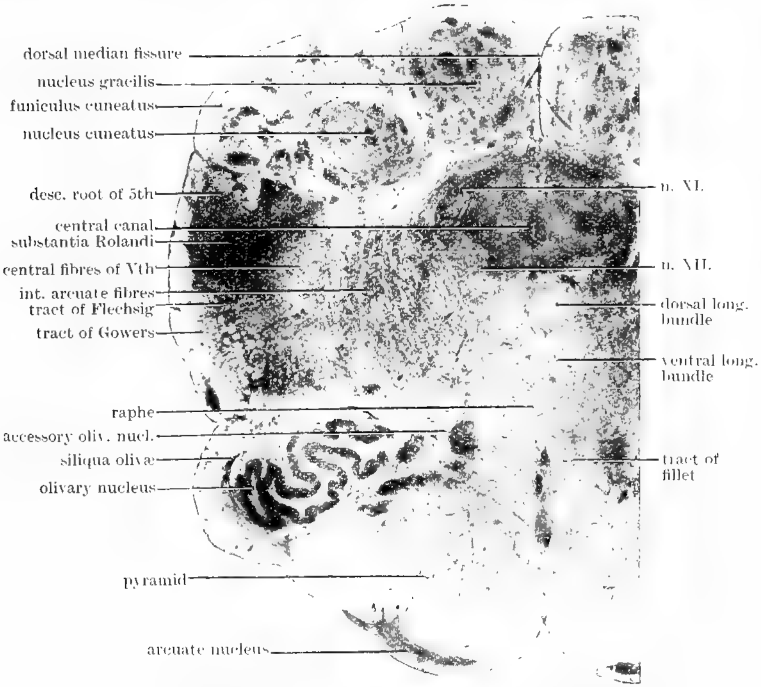

FIG. 597.—SECTION TAKEN IMMEDIATELY ABOVE THE DECUSSATION OF THE PYRAMIDS. Magnified 6½ diameters.

A section through the *region of the decussation of the pyramids* (fig. 596) has much the same form as a section through the upper part of the spinal cord; most of the structures of the cord can be recognised in it. A considerable alteration of the grey matter is, however, produced by the passage of the large bundles of the crossed pyramid tract from the lateral column of the spinal cord on each side through the base of the ventral horn and across the ventral median fissure to the opposite ventral column of the medulla oblongata, where, together with the fibres of the direct pyramid tract, which already lies in the ventral column of the cord, they constitute the prominent mass of white fibres which is seen on the ventral aspect of the medulla oblongata, on each side of the middle line, known as the *pyramid*. By this passage of fibres through the grey matter the tip of the ventral horn is cut off from the rest and is pushed to the side; part of it appears as an isolated mass or masses of grey matter, one of which is known as the *lateral nucleus.*

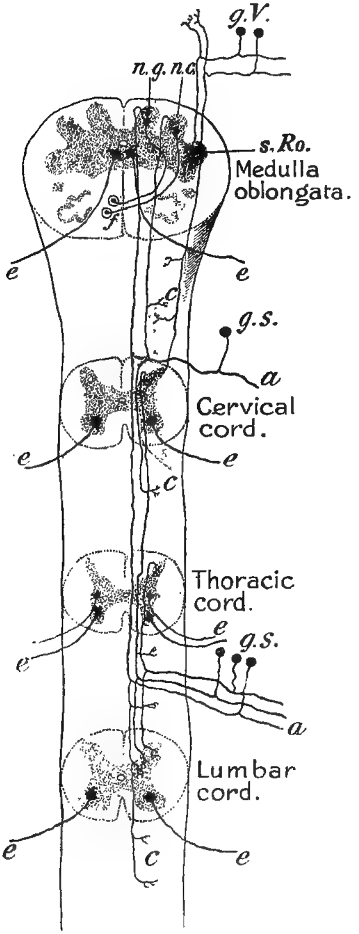

FIG. 598.—DIAGRAM TO SHOW THE COURSE OF THE DORSAL ROOT-FIBRES AFTER ENTERING THE CORD.

a, afferent fibres before entering ganglion; *g.s.*, spinal ganglion-cells; *g.V.*, ganglion of fifth nerve; *c*, descending branches (forming comma tract) giving off collaterals to grey matter. The ascending branches are shown partly ending in grey matter of dorsal horn, partly in the nucleus gracilis (*n.g.*) and nucleus cuneatus (*n.c.*) of the medulla oblongata; *s.Ro.*, substantia Rolandi; *f*, fibres of fillet arising in nuclei of medulla oblongata and crossing the raphe to the opposite side; *e*, efferent nerve-fibres from motor nuclei.

In sections a little higher, viz., *just above the decussation of the pyramids*, a wavy band of grey matter makes its appearance on the lateral aspect of each pyramid, corresponding with a prominence on the surface which is known as the *olive.* The wavy or plicated grey matter is termed the *olivary nucleus* (figs. 597, 599, 600).

The *pyramids* of the medulla oblongata are formed of fibres which originate in the frontal region of the cerebral cortex, and can be traced from the axons of the large cells in the grey matter of that cortex. The fibres course through the white matter of the hemisphere, through the middle third or more of the internal capsule and crusta, and through the pyramid bundles of the pons Varolii into these structures (pyramids) of the medulla oblongata. As we have just seen, they pass at the lower limit of the bulb chiefly to the opposite or crossed lateral column of the cord, but partly to the lateral column of the same side, and, in man and anthropoid apes, partly to the mesial part of the ventral white column. They collectively constitute the *tract of the pyramid,* which is smaller in the medulla oblongata than in the pons, since many of its fibres leave the main tract whilst within the pons and pass across the middle line towards the grey matter which lies in the dorso-lateral part of the pons and medulla oblongata, especially in that portion of the grey matter with which the sensory fibres of the cranial nerves are connected. Sometimes such a bundle of fibres, after passing towards the sensory nuclei in the lateral part of the medulla oblongata, does not end in them, but again comes ventralwards and joins the main or central part of the pyramid tract near its decussation (*bundle of Pick*).

It is not a little remarkable that although the fibres of the tract of the pyramid give off numerous collaterals to the grey matter of the cerebral cortex, the basal ganglia of the cerebrum, the substantia nigra of the mid-brain, the nuclei of the pons and the base of the dorsal horn of the spinal cord, no collaterals are seen to leave them in their course through the pyramids of the medulla oblongata, except a very few to the olivary nuclei. Various observers have professed to describe collaterals and terminations of the pyramid fibres as passing to the motor nuclei of the cranial nerves as well as to the motor cells in the ventral horn of the spinal cord, but statements to this effect must be received with caution, for although current in most text-books, they have not been substantiated by accurate observations. It is certain that most if not all of the fibres of the pyramid tract end not in the ventral but in the dorsal part of the spinal grey matter.

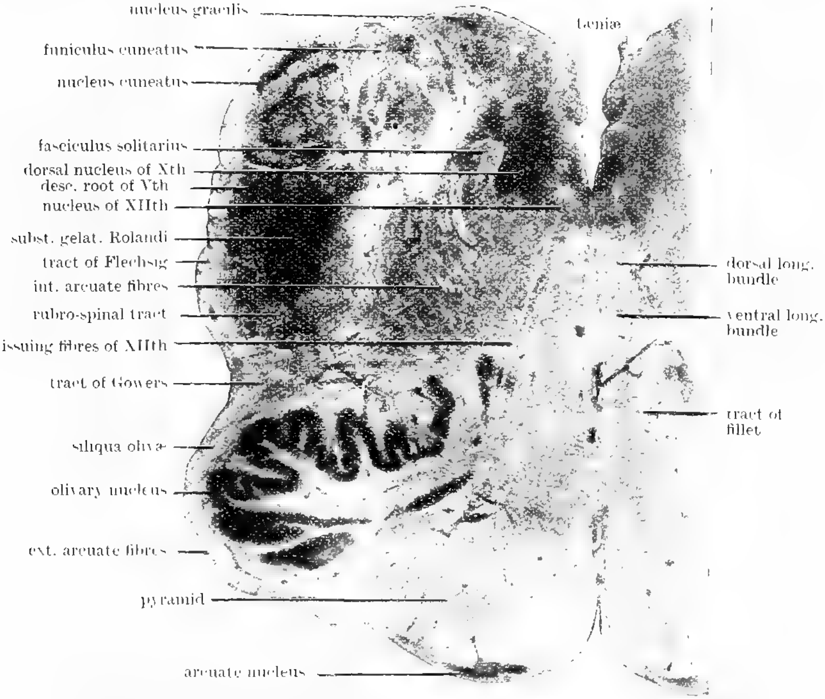

FIG. 599.—SECTION ACROSS THE MEDULLA OBLONGATA AT THE POINT OF THE CALAMUS SCRIPTORIUS OF THE FOURTH VENTRICLE. Magnified 6½ diameters.

In consequence of the increased development of the dorsal columns of white matter, a change also occurs in the grey matter of the dorsal horns, which in the medulla oblongata are pushed towards the side, the V which they form with one another being thus opened out; at the same time the tip of each horn becomes enlarged and causes a prominence upon the surface of the medulla oblongata, which is known as the *tubercle of Rolando*. Below, this is continuous with the substantia Rolandi of the apex of the dorsal horn of the cord. Above, its grey matter is prolonged into the sensory nucleus of the fifth nerve. On its outer side and partly embracing it is a bundle of fibres seen in every section of the medulla oblongata, and traceable up to the pons Varolii. This is the inferior or *descending root of the fifth nerve*—formerly known as the "ascending" root. Its fibres extend down as far as the upper cervical region of the spinal cord. Grey matter also soon becomes formed within the upward prolongations of the gracile funiculus (dorso-mesial column), and of the cuneate funiculus (dorso-lateral column), appearing at first as thin strands in the middle of the columns (fig. 596), but rapidly increasing in thickness (fig. 597) so as eventually to occupy almost the whole of them, forming the *nucleus gracilis* and the *nucleus cuneatus* respectively.

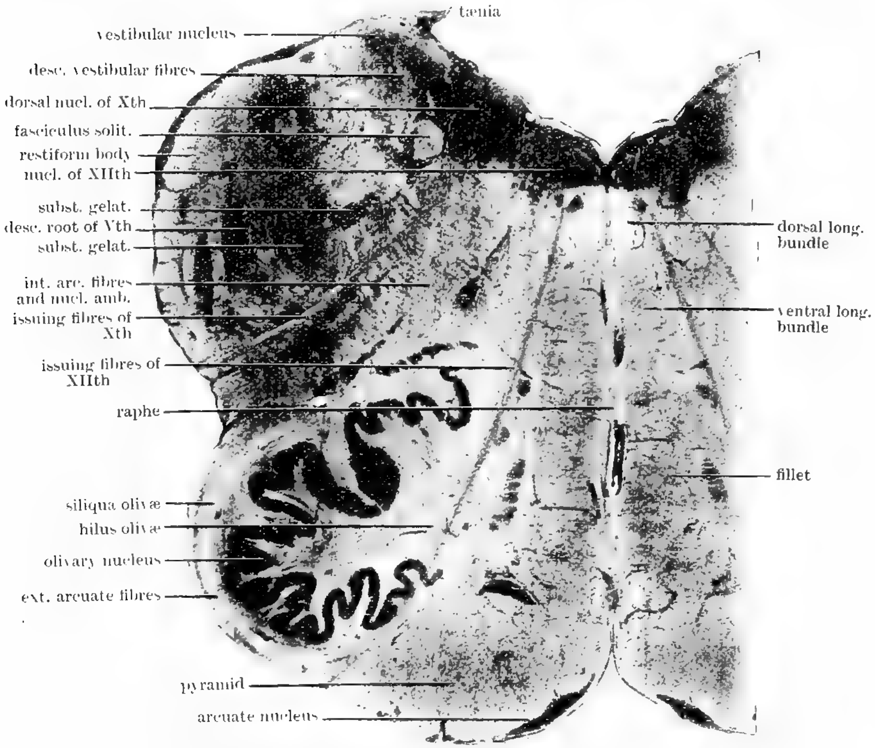

FIG. 600.—SECTION ACROSS THE MEDULLA OBLONGATA, AT ABOUT THE MIDDLE OF THE OLIVARY BODY. Magnified 6½ diameters.

It is in these nuclei that the fibres of Goll's and Burdach's tracts, which are continued up from the dorsal columns of the spinal cord, find their ultimate ending in complicated arborisations amongst the cells of the nuclei. These nuclei do not, however, receive all the ascending branches of the dorsal root-fibres, for a considerable number of these have already disappeared by entering the grey matter of the cord, in which they also end by arborisation amongst the cells. The cells of the nucleus gracilis and nucleus cuneatus are of small or moderate size with long dendrons. Their axons pass as internal arcuate fibres through the reticular formation into the inter-olivary layer, cross the median raphe dorsal to the pyramids (fig. 598, *f*), and then turn upwards, constituting the *tract of the fillet.* This tract, which in its lowest part is thus formed by the nerve-fibres which belong to the second relay (second neurones) of one of the sensory spinal paths, is reinforced in the higher regions of the medulla oblongata and in the pons by fibres derived from cells of the sensory nuclei of the cranial nerves. The majority of its fibres end in the lateral nucleus of the thalamus, but some pass to both the anterior and posterior corpora quadrigemina.

According to Van Gehuchten the fibres of the fillet which are derived from the nucleus cuneatus lie dorsally to those which are derived from the nucleus gracilis.

The continuation of the *central canal* of the spinal cord is still seen in the lower medulla oblongata (figs. 596, 597), but it comes nearer to the posterior surface and eventually opens out at the point of the calamus scriptorius of the fourth ventricle (fig. 599). The grey matter which surrounds it contains two well-marked groups of nerve-cells; the ventral of these is the lower part of the *nucleus of the hypoglossal* or twelfth nerve, the dorsal, with smaller cells, that of the *vago-accessory* or tenth and eleventh. But most of the grey matter of the crescent becomes broken up, by the passage of bundles of nerve-fibres through it, into a well-marked *reticular formation.* And instead of the comparatively narrow isthmus which joins the two halves of the spinal cord, a broad *raphe* now makes its appearance; this is formed of fibres coursing obliquely and ventro-dorsally, together with some grey matter containing nerve-cells.

In the section at *about the middle of the olive* (fig. 600), it will be seen that a marked change has been produced in the form of the medulla oblongata and the arrangement of its grey matter, by the opening out of the central canal into the fourth ventricle. This causes the grey matter which lower down surrounded the central canal to be spread out at the floor of that ventricle, and the collections of nerve-cells from which the hypoglossal and vagus nerves respectively arise, now, therefore, lie in a corresponding situation near the ventricular floor. At this level the outer small-celled group which corresponds with the nucleus of the spinal accessory in the lower part of the bulb has become the *dorsal nucleus of the vagus or tenth nerve*, and yet higher up the *dorsal nucleus of the glosso-pharyngeal or ninth nerve.* The nerve-bundles of the roots of these nerves can be seen in some of the sections (fig. 600) coursing through the thickness of the bulb and emerging, those of the hypoglossal just outside the pyramids, those of the vagus at the side of the medulla oblongata.

The dorsal part of the section is chiefly occupied by the grey matter of the floor of the fourth ventricle, and by fibres which are passing obliquely upwards and outwards towards the cerebellum, forming its inferior peduncle (*restiform body*). The grey matter forming the nucleus of the funiculus gracilis and of the funiculus cuneatus has now almost disappeared, but in place of these nuclei and near the outer part of the floor of the fourth ventricle are seen some masses of grey matter with a number of bundles of nerve-fibres amongst them. The grey matter is the lower part of the principal nucleus of the vestibular nerve (see p. 445), and the white bundles are formed of descending branches of the fibres of that nerve. Below these structures is the descending root of the fifth, with its nucleus mesial to it.

The ventral part of the section is occupied by the pyramid, and dorsal to this by a reticular formation (*reticularis alba*), composed of longitudinally coursing bundles of fibres belonging to the *tract of the fillet* and to the *dorsal and ventral longitudinal bundles*, interlaced with internal arcuate fibres that are passing across the raphe from the nuclei of the contralateral dorsal columns into the fillet, and from the opposite olive into the restiform body.

The middle portion of the section consists for the most part of a similar reticular formation, but with more grey matter and nerve-cells (*reticularis grisea*). This is a development of the formatio reticularis of the cervical cord, and the longitudinally coursing white bundles in it are probably formed of fibres derived from cells in the upper part of the cord. The nerve-cells of the grey reticular formation in the medulla oblongata give origin to fibres which bifurcate and pass both upwards to the same formation in the pons, and downwards towards the upper part of the cord, probably serving to associate these parts. Some also are said to give origin to arcuate fibres, which either traverse the raphe, or remain on the same side and eventually enter the cerebellum through the inferior peduncle (Van Gehuchten).

Ventro-laterally is the *olive*, within which is developed a peculiar wavy lamina of grey matter containing a large number of nerve-cells; this is the *dentate nucleus of the olive.* The lamina is incomplete at its mesial aspect (*hilus olivæ*), and here a large number of fibres issue, and, passing through the raphe, course as internal arcuate fibres to the opposite restiform body, and thus to the cerebellum. Some, however, turn sharply round and course below the dentate nucleus, forming an investment and capsule to it (*siliqua olivæ*), and pass towards the restiform body of the same side: the main connexion of the olivary nucleus is, however, with the cerebellar hemisphere of the opposite side. The olives receive numerous collaterals from the neighbouring white columns, including a few from the pyramids. Dorsal, or dorso-lateral to the olive, is the continuation upwards of the *ventral spino-cerebellar bundle* (tract of Gowers) of the spinal cord; the continuation of the *dorsal spino-cerebellar bundle* (tract of Flechsig), just above it, is now passing into the restiform body. Lastly a tract of fibres which originate within the thalamus passes over the lateral surface of the nucleus olivæ and ends within its grey matter (*thalamo-olivary tract, central tegmental tract* of Bechterew).

The cells of the dentate nucleus have numerous dendrons; their axons all pass towards the hilus, whence they emerge, and, for the most part, cross the raphe, pierce the opposite olivary nucleus, and pass, as already mentioned, into the restiform body (*olivo-cerebellar tract*).

Nerves arising from the medulla oblongata.—The twelfth, eleventh, tenth, ninth, and eighth nerves all take origin in the medulla oblongata, and their fibres may be seen emerging on each side, those of the twelfth ventrally between the pyramid and olive, and those of the other three nerves in succession at the side of the medulla oblongata between the olive and restiform body.

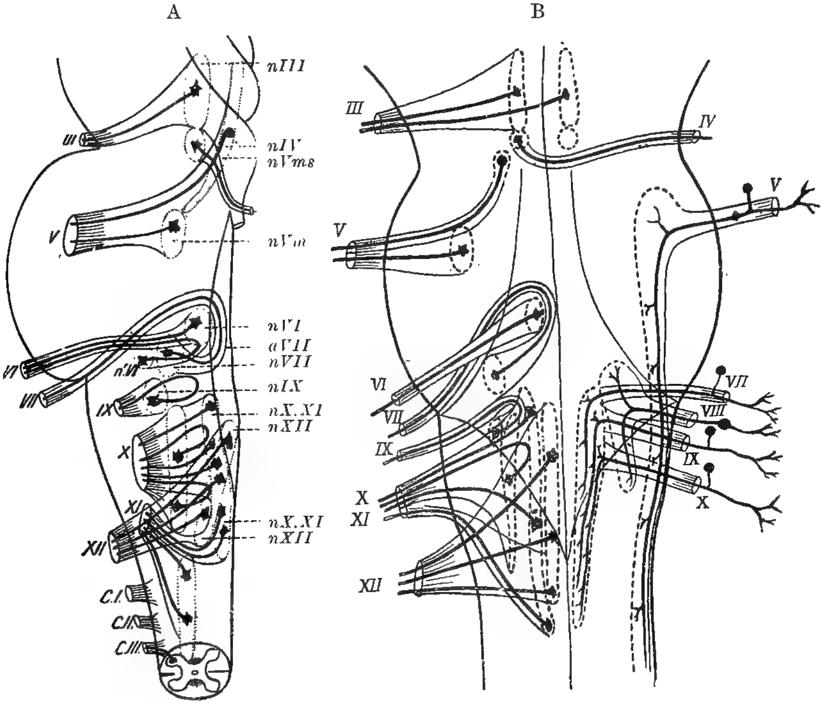

FIG. 601.—DIAGRAMS ILLUSTRATING THE ORIGIN AND RELATIONS OF THE ROOT-FIBRES OF THE CRANIAL NERVES.

A, efferent fibres only: profile view.
B, shows on the left the motor nuclei and efferent fibres (except those of the fourth nerve), and on the right side the afferent fibres: view from the dorsal aspect. The parts are supposed to be transparent.

The **twelfth** or **hypoglossal nerve** arises from a nucleus of large cells, similar to those of the ventral horn of the cord. This nucleus is situated:—in the lower part of the bulb, ventro-lateral to the central canal (fig. 597); in the upper part, near the floor of the fourth ventricle, close to the middle line (figs. 599, 600). None of the fibres cross to the opposite side; according to Van Gehuchten, this is true of all the cranial nerves, except a few fibres of the third nerve and the whole of the fourth nerve. The hypoglossal nucleus extends throughout the lower two-thirds of the bulb (fig. 601, *nXII.*). It receives many collaterals from adjacent sensory tracts in the reticular formation and from the descending sensory nuclei of the fifth, ninth, and tenth nerves, as well as from the dorsal longitudinal bundle. These form within the nucleus a plexus of fine fibrils which is highly characteristic. A similar plexus is seen in the oculo-motor nucleus.

Mesial to the hypoglossal nucleus, in the open part of the medulla oblongata, is the *nucleus of the fasciculus teres*, a column of moderate-sized cells which extends towards the lower margin of the pons and appears to receive fibres from the cerebellum (Edinger).

The **eleventh** or **spinal accessory nerve** begins to take origin from cells in the lateral part of the grey matter of the spinal cord as low down as the fifth cervical nerve. Its fibres from the cord (spinal fibres) are those to the (voluntary) sternomastoid and trapezius muscles. They pass from the cells of origin in the lateral part of the ventral horn (*motor nucleus*) at first dorsalwards; they then take a sharp bend outwards through the lateral column to emerge at the side of the cord and medulla oblongata.. The fibres which join the vagus (bulbar fibres) take origin in a nucleus of relatively small cells which lies dorso-laterally to the central canal of the medulla oblongata and behind the hypoglossal nucleus. This nucleus is continuous above with the corresponding nucleus of the vagus, and with it forms the *dorsal vago-accessory nucleus* (figs. 597, 599 to 601). Below, it extends nearly as far as the first cervical nerve; its upper part (vagal part) is in the floor of the fourth ventricle lateral to the hypoglossal nucleus, and reaches nearly as far as the lower border of the pons. Of the whole nucleus about the lower two thirds, *i.e.* as far as the lower end of the calamus scriptorius, give origin to fibres of the accessory. These fibres, as already stated, join the vagus, to which they supply certain motor fibres, including those of the thyro-arytenoid muscle (Van Gehuchten). The twelfth and eleventh nerves are entirely efferent.

The **tenth** or **vagus nerve (pneumogastric)** contains both motor (efferent) and sensory (afferent) fibres. The efferent fibres arise (1) from the upper part of the dorsal vago-accessory nucleus just described, (2) from a nucleus of grey matter containing large cells situated in the reticular formation (figs. 600, 602, *n.amb.*). This nucleus begins near the lower limit of the bulb and extends nearly to the facial nucleus, which it resembles in general position; it is known as the *nucleus ambiguus* or *ventral nucleus of the tenth nerve.* The axons of its cells are directed at first dorsalwards and inwards and then turn sharply round in the lateral direction to join the rest of the issuing fibres of the nerve, coursing in the same manner as the spinal fibres of the accessory; indeed, this nucleus is continuous below with the column of cells from which those fibres take origin.

The sensory fibres of the vagus take origin in the *ganglion of the root* and the *ganglion of the trunk* (*jugular* and *plexiform ganglia*), from unipolar cells like those of the spinal ganglia (fig. 602, *g*). They enter the medulla oblongata, and then bifurcate, one branch, a short (ascending) one, passing at once into an upper sensory nucleus, the other, a long one, descending. The upper sensory nucleus (*principal nucleus*), in which the short branches from the sensory root end, lies in grey matter near the floor of the ventricle, and is continuous with the grey matter which accompanies the *fasciculus solitarius* (figs. 599, 600, 602). This is formed by the descending fibres, with similar fibres of the twelfth and those of the *pars intermedia* of the seventh, and is to be regarded as the *descending root of facial, vagus, and glossopharyngeal.* It is traceable to the lower limit of the medulla oblongata; the fibres end in a nucleus of grey matter which lies along the mesial border of the root (*descending nucleus of facial, vagus, and glossopharyngeal*). This nucleus approaches the middle line as it descends, and in some animals terminates by joining its fellow of the opposite side over the central canal to form the *commissural nucleus* of Cajal.

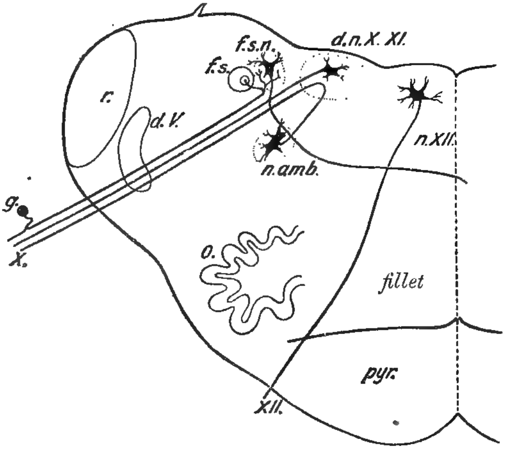

FIG. 602.—PLAN OF THE ORIGIN OF THE TWELFTH AND TENTH NERVES.

pyr, pyramid; ***n.XII.***, nucleus of hypoglossal; *XII.*, fibre of hypoglossal; *d.n.X.XI.*, dorsal nucleus of vagus and accessory; ***n.amb.***, nucleus ambiguus; *f.s.*, fasciculus solitarius (descending root of vagus and glossopharyngeal); *f.s.n.*, its nucleus; *X.*, emerging motor fibres of vagus; *g*, cell in ganglion of vagus giving origin to a sensory fibre; *d.V.*, descending root of fifth; *r*, corpus restiforme.

The **ninth** or **glossopharyngeal nerve** also contains both efferent and afferent fibres. The former have their cells of origin in a special nucleus (*motor nucleus of glossopharyngeal*) which occupies a position similar to that of the nucleus ambiguus, but lying mesial to the anterior end of that nucleus, and just below the nucleus of the facial. The afferent fibres of the nerve arise in the *jugular* or *upper* and in the *petrosal ganglia*, from unipolar cells like those of the spinal ganglia. Their central axons enter the medulla oblongata, and, like other sensory fibres, divide into two branches, ascending and descending. The course of these is like those of the vagus, the descending passing down in the fasciculus solitarius (extending to about one-third of its length, according to Bruce), and ending by arborising in the grey matter accompanying it (*descending root and its nucleus*), while the ascending branches pass nearly horizontally backwards and inwards to a nucleus (*principal nucleus*) beneath the inferior fovea of the fourth ventricle; this is continuous with the upper end of the nucleus of the descending root. The arrangement of the roots is almost exactly a counterpart of that of the vagus shown in the diagram given in fig. 602.

According to Edinger the sensory nuclei of these nerves receive fibres from the cerebellum; constituting a *cerebello-bulbar tract*, which is much better marked in lower vertebrates than in man and mammals.

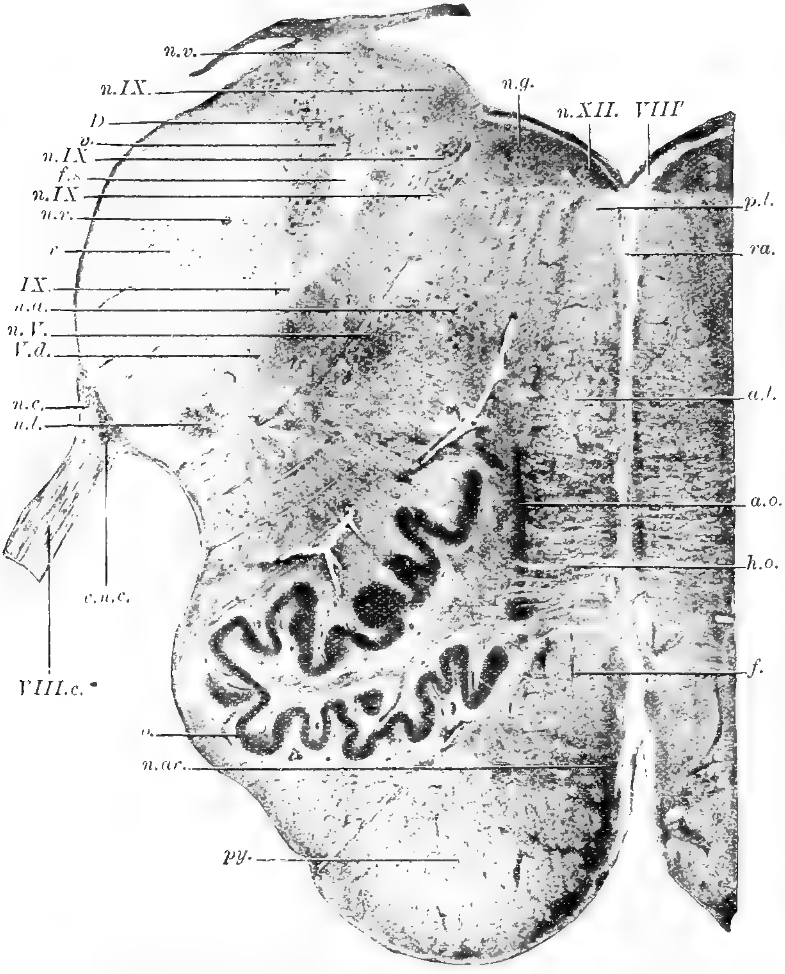

FIG. 603.—SECTION OF MEDULLA OBLONGATA AT THE LEVEL OF THE EIGHTH NERVE. Magnified about 6 diameters.

n.v., part of vestibular nucleus; *n.IX.*, parts of nucleus of ninth nerve; *D*, nucleus of Deiters; *v*, descending fibres of vestibular nerve; *f.s.*, fasciculus solitarius; ***n.r.***, small nucleus in restiform; *r*, restiform body; *IX.*, fibres of ninth nerve; ***n.a.***, nucleus ambiguus; ***n.V.***, sensory nucleus of fifth nerve; *V.d.*, descending root of fifth; *n.c.*, part of dorsal cochlear nucleus; *VIII.c*, cochlear division of eighth nerve; *c.n.c.*, ventral cochlear nucleus; *n.l.*, lateral nucleus; *o*, olivary nucleus; *n.ar.*, nucleus of arciform fibres; *py*, pyramid; ***n.g.***, grey matter in floor of fourth ventricle; *n.XII.*, nucleus of twelfth; *VIII'*, fibres of cochlear nerve entering raphe; *p.l.*, dorsal longitudinal bundle; *ra.*, raphe; *a.l.*, ventral longitudinal bundle; *a.o.*, accessory olivary nucleus; *h.o.*, fibres issuing from the hilus of the olive; *f*, fibres of fillet.

A section taken *through the uppermost part of the olivary prominence* will still show very much the same form and structural arrangements as that just described (fig. 603). The *nucleus of the hypoglossal* (figs. 603, 604, *n.XII.*) is still visible in the grey matter of the floor of the ventricle near the middle line, but the nerve which is now seen connected with the lateral part is the *eighth* or *auditory* (*VIII.*), the bundles of which, as they enter the bulb, embrace the inferior peduncle of the cerebellum (*corpus restiforme*, *c.r.*), which is now passing into that organ. The origin of the *eighth nerve* is thus subdivided into two principal parts, known respectively as the *dorsal* or *cochlear* and the *ventral* or *vestibular* divisions (fig. 604).

The eighth nerve.—The fibres of the cochlear division take origin in the *ganglion of the cochlea*; those of the vestibular division in the *ganglion of Scarpa.* These ganglia, which are situated at the periphery, the former within, the latter near the internal ear, are composed of bipolar cells, of which the peripheral axons end by ramifying amongst the cells of the sensory epithelium, and the central axons form the cochlear and the vestibular divisions of the auditory nerve and pass into the medulla oblongata in the manner here described.

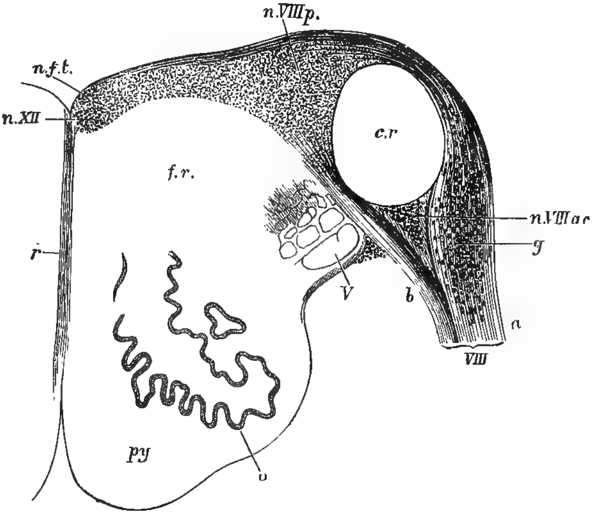

FIG. 604.—TRANSVERSE SECTION OF THE UPPER PART OF THE MEDULLA OBLONGATA. Four times the natural size. (Schwalbe.)

py, pyramid; *o*, olivary nucleus; *V*, descending root of the fifth nerve; *VIII*, root of the auditory nerve, formed of two parts, *a*, cochlear, and *b*, vestibular, which enclose the restiform body, *c.r.*; *n.VIIIp*, principal nucleus of the vestibular division; *n.VIIIac*, ventral or accessory nucleus of the cochlear division; *g*, dorso-lateral nucleus of the cochlear division; *n.f.t.*, nucleus of the funiculus teres; *n.XII*, nucleus of the hypoglossal; *r*, raphe; *f.r.*, reticular formation.

The fibres of the **dorsal** or **cochlear division** (**cochlear nerve**) bifurcate as they enter the medulla oblongata. Each fibre divides into a thick and a thin branch. The thicker branches pass partly to a mass of ganglion-cells which is wedged in between the two roots and the restiform body, and is known as the *ventral* or *accessory auditory nucleus* (figs. 604, 605, *n.acc.*), applying themselves with a peculiar form of terminal arborisation (fig. 221) to the cells of this nucleus; partly over the restiform body to terminate in a prominent mass of grey matter which overlies that body, and also extends to the lateral part of the floor of the fourth ventricle at its widest part (*dorso-lateral nucleus, tuberculum acusticum*). The cells of the tubercle have a peculiar spindle shape and are set vertically to the surface. They begin to appear in the root itself, lying amongst the fibres of the nerve. Here they are sometimes spoken of as forming the "ganglion of the root." The thinner branches of the bifurcated cochlear fibres pass downwards for a certain distance and break up into a plexus of fine fibrils.

These two nuclei, viz., the accessory nucleus and the acoustic tubercle, are the nuclei of ending of the cochlear fibres. From their nerve-cells new fibres arise which continue the auditory path centrally (see fig. 605). Those from the accessory nucleus enter the *trapezium*—which consists of transverse fibres running behind the pyramid bundles of the pons Varolii—and pass in it partly to the superior olive and trapezoid nucleus of the same side of the pons, but mostly to the corresponding structures of the opposite side. Some end in those nuclei, but others merely traverse them, giving off numerous collaterals to them and to the *superior olives* and other nuclei near by (see pons), and then turn upwards in the lateral part of the tract of the fillet to pass ultimately towards the inferior corpora quadrigemina; in tending towards these structures at the side of the mid-brain they form the *lateral fillet*, or *fillet of Reil*, which is there conspicuous. Some of the fibres from the cells of the accessory nucleus do not pass directly to the trapezium, but first curve round the restiform body (Held); these form the most dorsally situated fibres of the trapezium. The fibres which arise in the acoustic tubercle pass for the most part over the floor of the fourth ventricle, where they are seen superficially as the *medullary* or *acoustic striæ* (fig. 605), and entering the raphe, traverse it in a dorso-ventral direction; they then join the others from the accessory nucleus in their course to the superior olive and lateral fillet of which they constitute the deeper layer. A few fibres are directed into the fillet of the same side as their cells of origin.

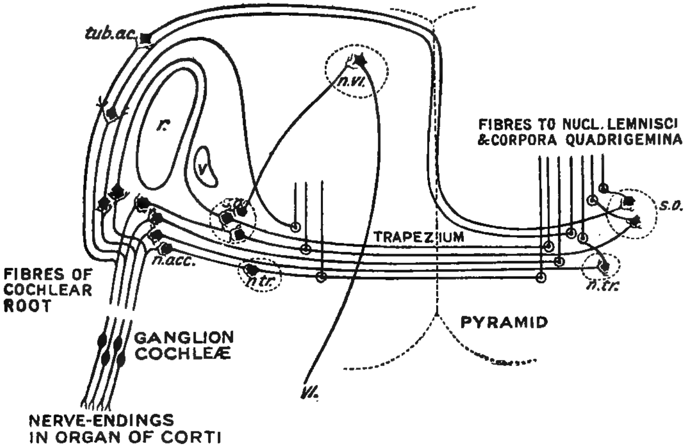

FIG. 605.—PLAN OF THE COURSE AND CONNEXIONS OF THE FIBRES FORMING THE COCHLEAR ROOT OF THE AUDITORY NERVE.

r, restiform body; *V*, descending root of the fifth nerve; *tub.ac.*, tuberculum acusticum; *n.acc.*, accessory nucleus; *s.o.*, superior olive; *n.tr.*, nucleus of trapezium; *n.VI.*, nucleus of sixth nerve; *VI.*, issuing root fibre of sixth nerve. The "acoustic striæ" are seen at the dorsal part of the section.

Edinger states that, at least in the dog, all the fibres of the trapezium end in its nucleus or in the superior olivary nucleus, the central acoustic path being wholly continued, so far as the trapezium fibres are concerned, by fresh neurones, the cell-bodies of which lie in those nuclei, and the axons of which pass into the lateral fillet. On the other hand, from the cells in the tuberculum acusticum, the axons are said to be continued upwards in the opposite lateral fillet without the intervention of any corresponding nuclei. The lateral fillets pass above into the posterior corpora quadrigemina.

The accessory nucleus also *receives* fibres from the trapezium, which end by ramifying amongst its cells. These are perhaps derived from the accessory nucleus of the opposite side. Both sets of fibres (from the accessory nucleus and tuberculum) give off collaterals near their origin, which terminate within these nuclei.

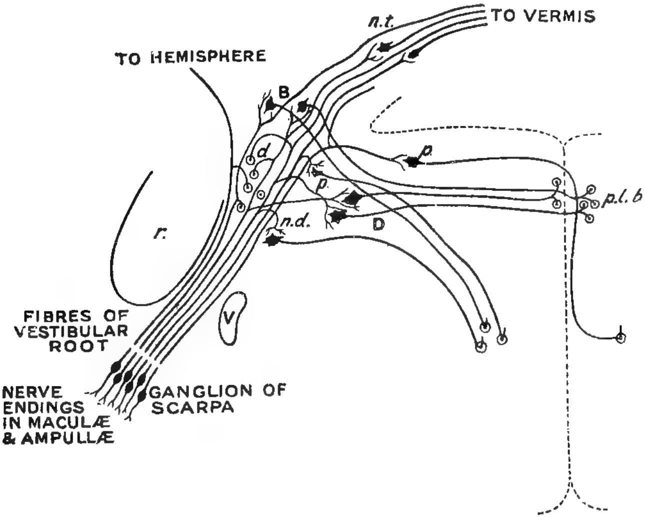

FIG. 606.—PLAN OF THE COURSE AND CONNEXIONS OF THE FIBRES FORMING THE VESTIBULAR ROOT OF THE AUDITORY NERVE.

r, restiform body; *V*, descending root of fifth nerve; *p.*, cells of principal nucleus of vestibular root; *d*, fibres of descending vestibular root; *n.d.*, a cell of the descending vestibular nucleus; D, cells of nucleus of Deiters; B, cells of nucleus of Bechterew; *n.t.*, cells of nucleus tecti (fastigii) of the cerebellum; *p.l.b.*, fibres of the dorsal longitudinal bundle. No attempt has been made in this diagram to represent the actual positions of the several nuclei. Thus a large part of Deiters' nucleus lies dorsal to and in the immediate vicinity of the restiform body.

The **ventral** or **vestibular division (vestibular nerve)**, which enters a little in front of (above) the cochlear division, passes between the restiform body and the descending root of the fifth (fig. 606), to enter a mass of grey matter containing for the most part cells of small size, which is termed the *principal* or *dorsal nucleus* of the vestibular division. Here each of its fibres bifurcates with a Y-shaped division into an ascending and descending branch (fig. 606). The descending branches are collected into small bundles (*descending vestibular root*) which run downwards towards the lower part of the medulla oblongata, and gradually end by arborising around cells in the adjacent grey matter (*descending vestibular nucleus*), which is continued down from the principal nucleus. The ascending branches pass upwards on the inner side of the restiform body towards the nucleus tecti of the cerebellum. In their course they give off numerous collaterals which arborise round the large cells of two nuclei which occur in this part of the medulla oblongata and pons near the outer part of the floor of the fourth ventricle. These two nuclei are termed respectively the *nucleus of Deiters* and the *nucleus of Bechterew* (fig. 606).

Van Gehuchten states that the nucleus of Bechterew alone receives fibres from the ascending branches and that all the other nuclei (dorsal, descending, and nucleus of Deiters) are furnished with fibres from the descending branches.

The *nucleus of Deiters* is especially characterised by the large size of its cells and by the manner in which they are enveloped as by a basket work by the ramifications of the collaterals in question. From these cells fibres arise which pass to the dorsal (posterior) longitudinal bundles of both sides: in these the fibres bifurcate (Cajal), one branch passing upwards to the oculomotor nucleus and giving off collaterals to the nucleus of the sixth nerve, and the other downwards, eventually reaching the ventral column of the spinal cord (ventro-lateral descending tract), and terminating by arborisations amongst the cells of the ventral horn (see p. 424). By means of the collateral fibres which supply the sixth and oculomotor nuclei it is probable that the conjugate movements of the two eyes are brought about, and by the fibres to the spinal cord the associated movements of the head and trunk. Fibres have also been described as passing from Deiters' nucleus to the nucleus tecti of the cerebellum. Owing to its connexion with the semicircular canals, the cerebellum, the oculomotor nuclei, and the nuclei in the ventral horn of the spinal cord, this nucleus must exercise important functions in connexion with co-ordination of head and eye movements and equilibration in general.

The fibres which originate in the *nucleus of Bechterew* pass into the reticular formation and become longitudinal,. but their destination is not certainly known. Some are said to pass into the ventral column of the cord.

The *reticular formation* still occupies the greater part of each lateral half of the bulb between the grey matter at the floor of the fourth ventricle and the pyramids, and a small portion of the *olivary nucleus* may still be seen. The descending root of the fifth nerve with its adjacent grey matter is conspicuous.

The *restiform body* is formed (1) of the fibres of the dorsal spino-cerebellar tract of the same side, which are derived below from cells of Clarke's column, and pass above into the middle lobe of the cerebellum, (2) of fibres from the opposite olivary nucleus, and (3) of fibres from the olivary nucleus of the same side. The olivary fibres pass mainly to the cerebellar hemisphere. According to some authorities the restiform body also contains fibres derived from the nucleus gracilis and nucleus cuneatus of the opposite side, as well as some from a nucleus which lies just outside the main mass of grey matter of the funiculus cuneatus, and is known as the *outer cuneate nucleus.*

Fourth ventricle.—The *floor* is covered by a layer of ciliated epithelium-cells, continuous below with those lining the central canal, and above, through the aqueduct, with the epithelium of the third and lateral ventricles. The epithelium rests upon, and its cells assist in forming, a layer of neuroglial tissue known as the *ependyma* of the ventricle. The fourth ventricle is roofed over by a layer of pia mater, with projecting choroid plexuses; the under surface of these is covered by a thin epithelial layer continuous at each side with the ciliated epithelium of the floor. The roof becomes somewhat thickened as it is continued into the ependymal layer of the floor of the ventricle; this thickened part (*tænia* or *ligula*, figs. 599, 600) is often left attached when the thin epithelial roof is removed along with the pia mater which covers it.

LESSONS XLII. AND XLIII.

THE PONS VAROLII, MESENCEPHALON, AND THALAMENCEPHALON.

1. Sections through the lower, middle, and upper parts of the pons Varolii.

2. Sections across the region of the corpora quadrigemina, one at the level of the inferior, the other at the level of the superior, pair.

3. A section across the posterior part of the third ventricle passing through the thalami.

In all the above sections sketch under a low power the general arrangement of the grey and white matter, inserting the positions of the chief groups of nerve-cells.

[The tissue is hardened and the sections are prepared, stained, and mounted in the same way as the spinal cord and medulla oblongata.]

THE PONS VAROLII.

Sections through the **lower part of the pons** (fig. 607) show much the same arrangement of grey and white matter as that met with at the upper part of the medulla oblongata, but the general appearance of the sections is much modified by the presence of a large number of transversely coursing bundles of nerve-fibres, most if not all of which are passing to the hemispheres of the cerebellum (fibres of middle peduncle of cerebellum). Some of the most anterior of these peduncular fibres often form a detached bundle which is known as the *tænia pontis*. In the interstices of the transverse bundles is a considerable amount of grey matter (*nuclei pontis*) from the cells of which the fibres of the middle peduncle of the opposite side are derived. Amongst the cells of the nuclei pontis many collaterals of the pyramid tracts end, and the cortico-pontine fibres (see below) also terminate here; in this way is formed a connexion between the cerebral hemisphere of the one side and the cerebellar hemisphere of the opposite side. The continuation of the pyramids of the medulla oblongata in the pons takes the form of a number of separate bundles (fig. 607, *py.*) which run between the transverse bundles. These bundles are collectively much more bulky than the pyramids of the medulla oblongata, for, in addition to fibres of the pyramid tract proper (*cortico-spinal*), derived from the motor area of the cortex, they are largely composed (especially the dorso-lateral bundles) of other fibres (*cortico-pontine*) connecting the cortex with this part of the hind-brain. The pyramid bundles are separated from the reticular formation by deeper transverse fibres, which belong to a different system from those of the middle peduncle. They form what has already been referred to as the *trapezium* (figs. 605, 607); a collection of fibres which forms part of the central auditory path; some appear to be commissural between the auditory nuclei of the two sides. The fibres of the trapezium traverse a collection of nerve-cells which lies mesial and ventral to the superior olivary nucleus, known as the *nucleus of the trapezium* (fig. 605, *n.tr.*).

This nucleus is characterised by the peculiar chalice-like synapses which the entering axons of the larger acoustic fibres form with the cell-bodies (Held). According to Cajal these large fibres are continued directly from the root-fibres of the cochlear nerve, and are not derived from the cells of its accessory nucleus.

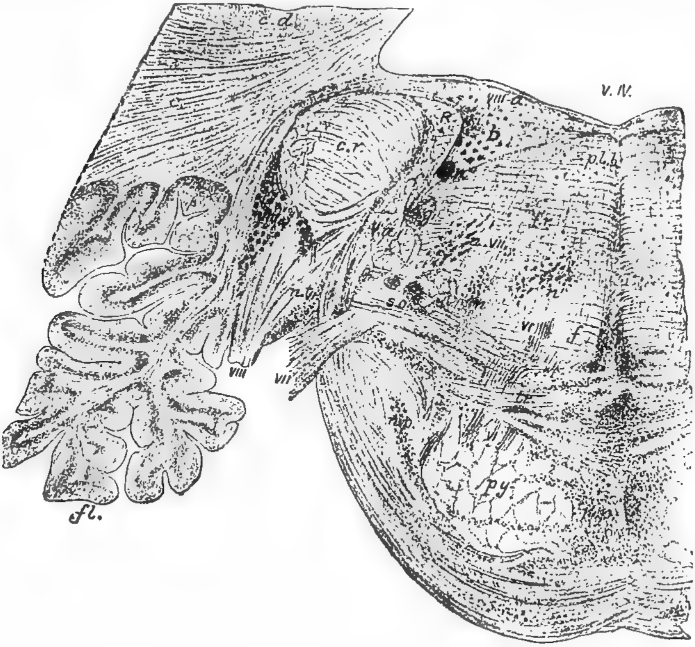

FIG. 607.—TRANSVERSE SECTION THROUGH THE LOWERMOST PART OF THE PONS. From a photograph. Magnified 4 diameters.

r.IV., fourth ventricle; *c*, white matter of cerebellar hemisphere; *c.d.*, corpus dentatum; *fl.*, flocculus; *c.r.*, corpus restiforme; *R*, bundle of Roller, composed of the descending branches of the vestibular nerve; *D*, nucleus of Deiters; *VIII.*, issuing root of auditory nerve; *VIII.d.*, principal or dorsal nucleus of the vestibular nerve; *VIII.c.*, nucleus of cochlear nerve; *tr.*, trapezium; *n.tr.*, its nucleus; *f*, fillet; *p.l.b.*, dorsal longitudinal bundle; *f.r.*, formatio reticularis; *n*, *n'*, *n''*, various nuclei within it; *V.a.*, descending root of fifth nerve; *s.g.*, substantia gelatinosa; *s.o.*, superior olive; *VII.*, issuing root of facial nerve; *n.VII.*, its nucleus; *VI.*, root-bundles of sixth nerve; *py.*, pyramid bundles; *n.p.*, nuclei pontis.

The olivary nucleus is no longer seen, but there are one or two small collections of grey matter, more conspicuous in some animals than in man, which lie in the ventral part of the reticular formation, known as the *superior olivary nucleus* (*o.s.*), the *pre-olivary nucleus*, and the *semilunar nucleus* (Cajal). All these, as well as the nucleus of the trapezium itself, are connected with the fibres of the trapezium which form the central auditory path; these fibres either ending in the nuclei in question or giving off to them numerous collaterals; whilst from the cells of the nuclei axons pass into the trapezium or into the adjacent lateral part of the fillet.

On the other hand, the superior olive is said to receive some fibres from the posterior colliculi of the corpora quadrigemina. The *nucleus of Deiters*, which begins to appear in the upper part of the medulla oblongata, where it has been already studied (p. 446), extends into the pons Varolii; where it lies near the floor of the fourth ventricle, a little mesial to the restiform body (*D*, fig. 607). The nerve-fibres connected with its cells pass towards the middle line and enter the *dorsal longitudinal bundle*. Here, as already stated, they divide, one branch passing upwards in the bundle and terminating by arborescence chiefly in the opposite oculomotor nucleus: the other branch extending downwards in the medulla oblongata and cord. In the spinal cord they are found in the ventro-lateral descending tract: fibres from each nucleus of Deiters occur in both of these tracts (E. H. Fraser). They terminate by arborescences in the ventral horn of the spinal cord.

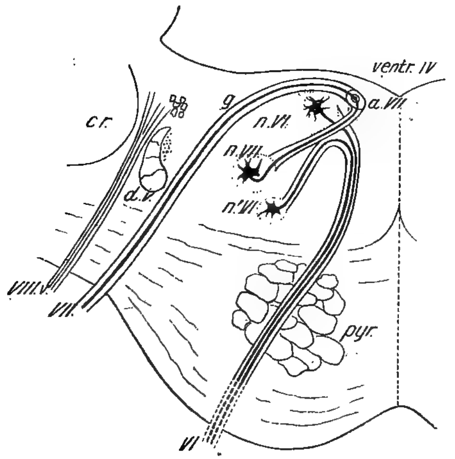

FIG. 608.—PLAN OF THE ORIGIN OF THE SIXTH AND SEVENTH NERVES.

VI., sixth nerve; *VII.*, seventh nerve; *a.VII.*, ascending part of root of seventh shown cut across near the floor of the fourth ventricle; *g*, genu of seventh; *n.VI.*, chief nucleus of the sixth nerve; *n'.VI.*, accessory nucleus of sixth; *n.VII.*, nucleus of seventh; *d.V.*, descending root of fifth; *pyr.*, pyramid bundles; *VIII.v.*, vestibular root of eighth nerve.

The nerves which enter or emerge from the grey matter of this region of the brain are part of the *eighth*, the *seventh*, the *sixth*, and somewhat higher up the *fifth* cranial nerve. Of these the eighth (already considered) and fifth are connected with groups of nerve-cells which occupy the grey matter opposite the external border of the floor of the ventricle; the sixth with a nucleus which is placed in the grey matter of the floor of the ventricle but nearer the middle line, and the seventh with a special nucleus which lies in the formatio reticularis.

The VIIth or facial nerve and the nerve of Wrisberg (pars intermedia).—The motor fibres of the *seventh nerve* arise from the facial nucleus in the formatio reticularis. This nucleus is homologous with the nucleus ambiguus seen in sections of the medulla oblongata. It has been shown that the motor fibres to the stapedius arise from the mesial part of the nucleus and then in succession those to the external ear muscles, those to the mouth and face muscles, and, finally, from a group of cells situated dorsally to the rest, the motor fibres supplied from the superior branch of the facial (Marinesco, Van Gehuchten). From the nucleus of origin the fibres first pass obliquely backwards to the floor of the ventricle, then longitudinally upwards for a short distance (fig. 601, A; fig. 608), and finally bend obliquely forwards and downwards to emerge between the transverse fibres at the side of the pons. None of the fibres of the seventh are derived from the nucleus of the sixth, as has sometimes been thought to be the case. As they curve over that nucleus the fibres of the seventh give off fine branches which cross the raphe; their destination is unknown. The nucleus of the facial receives collaterals from the adjacent sensory tracts in the formatio reticularis.

The facial is not a purely motor nerve, but has a ganglion upon it of the spinal type (*geniculate ganglion*) from which fibres arise (fig. 601, B) which pass centrally into the pars intermedia of Wrisberg. This last enters the pons between the seventh and eighth nerves, and its fibres bifurcate into ascending and descending branches like other sensory nerves; the descending branches pass into the solitary bundle and end like those of the glossopharyngeal in the upper part of its accompanying grey matter. The peripheral axons of the cells of the geniculate ganglion pass into the large superficial petrosal and chorda tympani—to which they probably furnish gustatory fibres. Other (efferent) fibres pass into the pars intermedia and ultimately into the chorda tympani from certain moderately large cells in

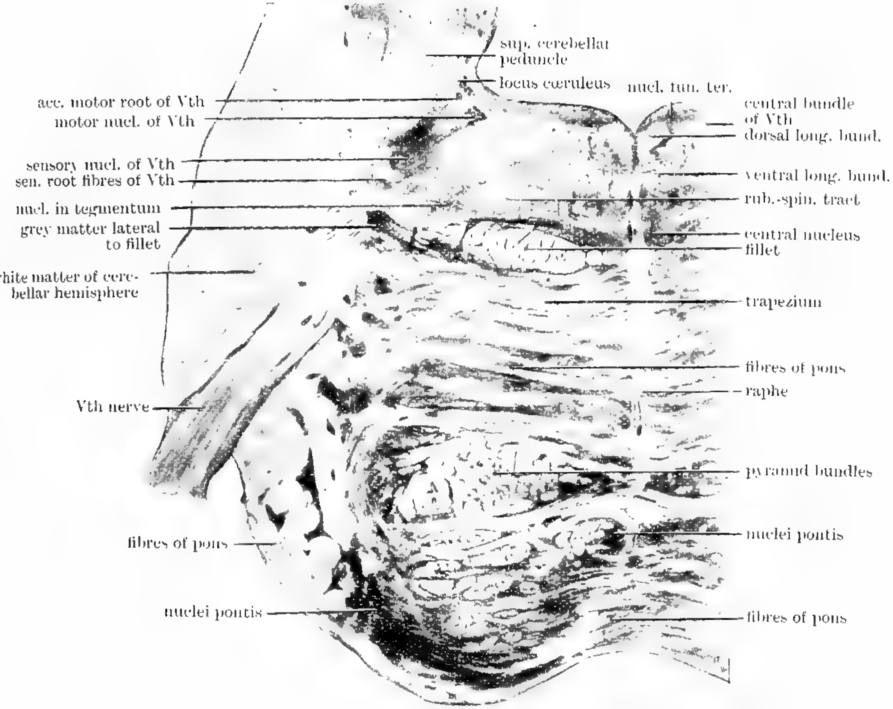

FIG. 609.—SECTION ACROSS THE MIDDLE OF THE PONS VAROLII. Photograph. Magnified about 4 diameters.

the dorsal part of the facial nucleus. These are probably the fibres of the chorda to the submaxillary and sublingual salivary glands.

The sixth nerve (abducens).—The fibres of the *sixth nerve* (figs. 601, 608), which are purely motor, pass out from the mesial aspect of the nucleus and turn forwards; traversing the pyramid bundles they emerge at the lower margin of the pons. A few fibres are derived from a small *ventral nucleus* lying near the nucleus of the facial; these run at first backwards and then turn forwards to join the others (Van Gehuchten) (fig. 608, *n'. VI.*).

The **fifth** or **trigeminal nerve** emerges at the side of the pons in two roots, a smaller motor and a larger sensory (fig. 610).

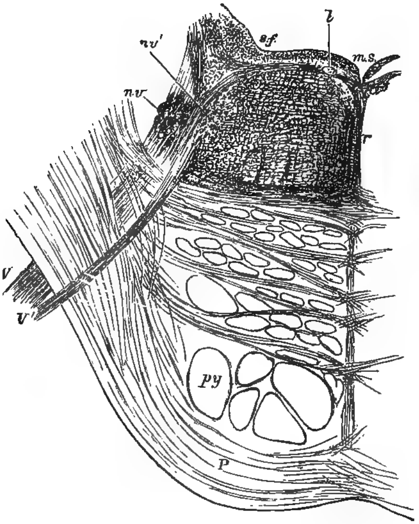

FIG. 610.—SECTION TAKEN SOMEWHAT OBLIQUELY THROUGH THE PONS FOLLOWING THE COURSE OF THE ISSUING ROOTS OF THE FIFTH NERVE.

m.s., median sulcus; *l*, dorsal longitudinal bundle; *s.f.*, substantia ferruginea; *n.v*, sensory, and *n.v'*, motor nucleus of fifth; *V*, sensory, and *V'*, motor roots of fifth; *r*, raphe; *py*, pyramid bundles; *p*, transverse fibres of middle peduncle of cerebellum.

The *motor root* is derived partly from fibres which arise in the upper part of the pons and lower part of the mesencephalon from large spherical unipolar nerve-cells lying at the side of the grey matter bounding the Sylvian aqueduct (*accessory* or *superior motor nucleus of fifth*, fig. 601, *nVms*; fig. 611, *m'.n.V.*), partly from the *motor nucleus proper* (figs. 601, *nVm*; 611, *m.n.V.*) which lies in the grey matter at the lateral edge of the fourth ventricle (figs. 609, 610). As they pass the motor nucleus proper the fibres from the superior or accessory nucleus give off into it a large number of collaterals which ramify between and around its cells.

The fibres of the *sensory root* are derived from the cells of the Gasserian ganglion which are homologous with the cells of the spinal ganglia. These fibres of the sensory root when traced into the pons are found to bifurcate, the ascending branches ending in a mass of grey matter (*principal sensory nucleus of the fifth*, fig. 611, *p.s.n.V.*) lying just lateral to the motor nucleus, while the descending branches trend downwards into the medulla oblongata where they form the descending or spinal root of the fifth (fig. 611, *d.s.V.*); some even reach the upper part of the spinal cord. They lie immediately lateral to and in close connexion with the substantia gelatinosa Rolandi which forms the *inferior sensory nucleus* (*d.s.n.V.*); it is continued above into the principal nucleus. The substantia gelatinosa which forms the sensory nucleus of the fifth contains numerous nerve-cells, both small and large; many of the small cells are grouped into nest-like clusters (*islands of Calleja*). The axons of the larger cells pass for the most part across the raphe to the formatio reticularis of the opposite side, where they reinforce the ascending fibres of the intermediate fillet, but some ascend in the fillet of the same side; others pass to a special *ascending bundle* of fibres on the opposite side of the raphe which lies nearer the floor of the fourth ventricle, and in the tegmentum of the mid-brain lies lateral to the dorsal longitudinal bundle; hence it is continued upwards into the thalamus. Collaterals are given off from these ascending fibres to the adjoining grey matter, and especially to the nucleus of the facial nerve. Branches also pass downwards into the formatio reticularis.

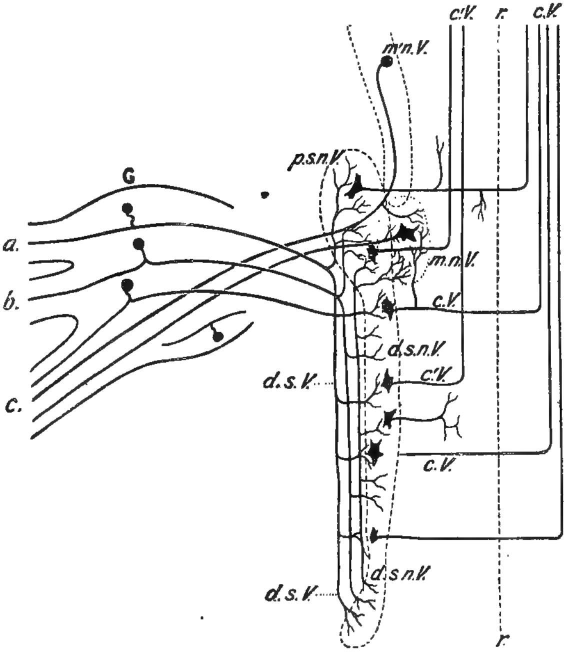

FIG. 611.—PLAN (LONGITUDINAL) OF THE ORIGIN OF THE FIBRES OF THE FIFTH NERVE.

G, Gasserian ganglion; *a*, *b*, *c*, three divisions of the nerve; *m'.n.V.*, superior motor nucleus; *m.n.V.*, principal motor nucleus; *p.s.n.V.*, principal sensory nucleus; *d.s.n.V.*, descending sensory nucleus; *d.s.V.*, descending root; *c.V.*, *c'.V.*, central sensory tracts composed of fibres emanating from the sensory nuclei; *r*, plane of the raphe.

Descending tracts in the pons and medulla oblongata—Tract of the pyramid.—The fibres of this tract are much more numerous in the pons than in the medulla oblongata. They send numerous collaterals into the grey matter of the nuclei pontis (fig. 612, A).

The *cortico-bulbar tract* lies mesial to the fillet (see p. 457). It consists of fibres passing from the motor cortex towards the nuclei of the facial and hypoglossal. In the crusta of the mid-brain these fibres lie mesial to the ordinary pyramid fibres, but they then leave the latter and pass into the ventral part of the tegmentum and are continued downwards in the formatio reticularis into the medulla oblongata.

The *dorsal (posterior) longitudinal bundle* forms another very distinct tract. It contains both ascending and descending fibres and runs just ventral to the grey matter of the floor of the fourth ventricle, near the middle line. As already noticed it connects Deiters' nucleus with the oculomotor nucleus, the nucleus of the sixth, and the ventral horn cells of the spinal cord; it probably also receives fibres from the axons of some of the large cells of the formatio reticularis.

Other descending tracts in the pons which are not so distinctly marked in the normal condition, but which can be traced by special methods, are: 1. *The rubro-spinal tract*; 2. *The ventral longitudinal bundle*; 3. *The ponto-spinal lateral tract*; 4. *The vestibulo-spinal tract*; 5. *The central tract of the tegmentum.*

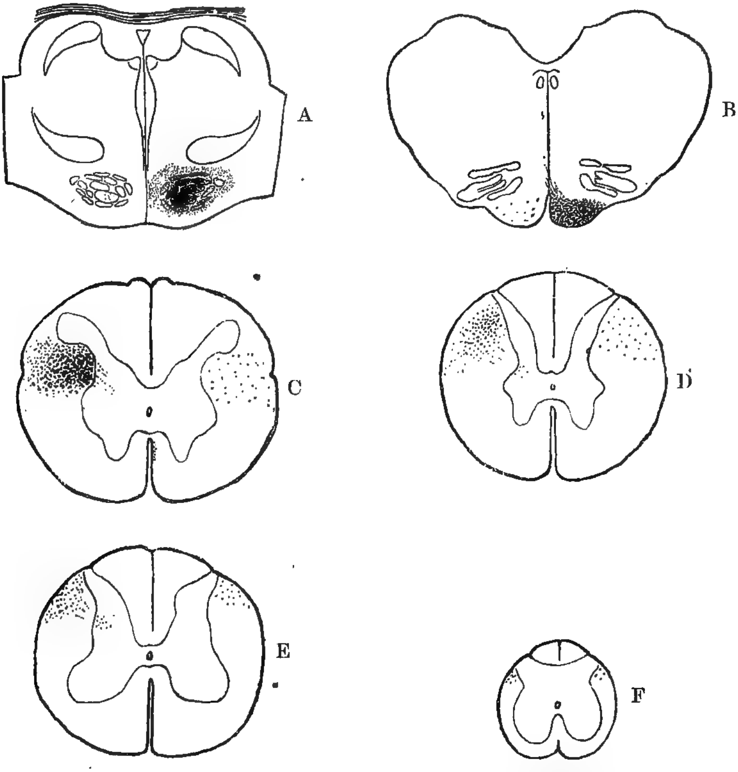

Fig. 612.—Section of pons (A), medulla oblongata (B), of cervical (C), thoracic (D), lumbar (E), and sacral (F) regions of spinal cord of monkey which had suffered removal of the precentral gyrus of the right cerebral hemisphere.

The sections are stained by the Marchi method.

Monakow's bundle or *the rubro-spinal tract* has already been seen as the prepyramidal tract of the spinal cord (p. 424). Its fibres arise from the cells of the red nucleus of the mid-brain of the opposite side, crossing the raphe in Forel's decussation (p. 462, footnote). In the upper part of the pons it is dorsal to the mesial fillet, but lower down runs in the lateral part of the tegmentum, dorsal to the lateral fillet.

The ventral longitudinal bundle (*tecto-spinal tract*) consists of fibres which arise in the opposite superior quadrigeminal body. These cross the raphe in Meynert's decussation (p. 462), and run down ventral to

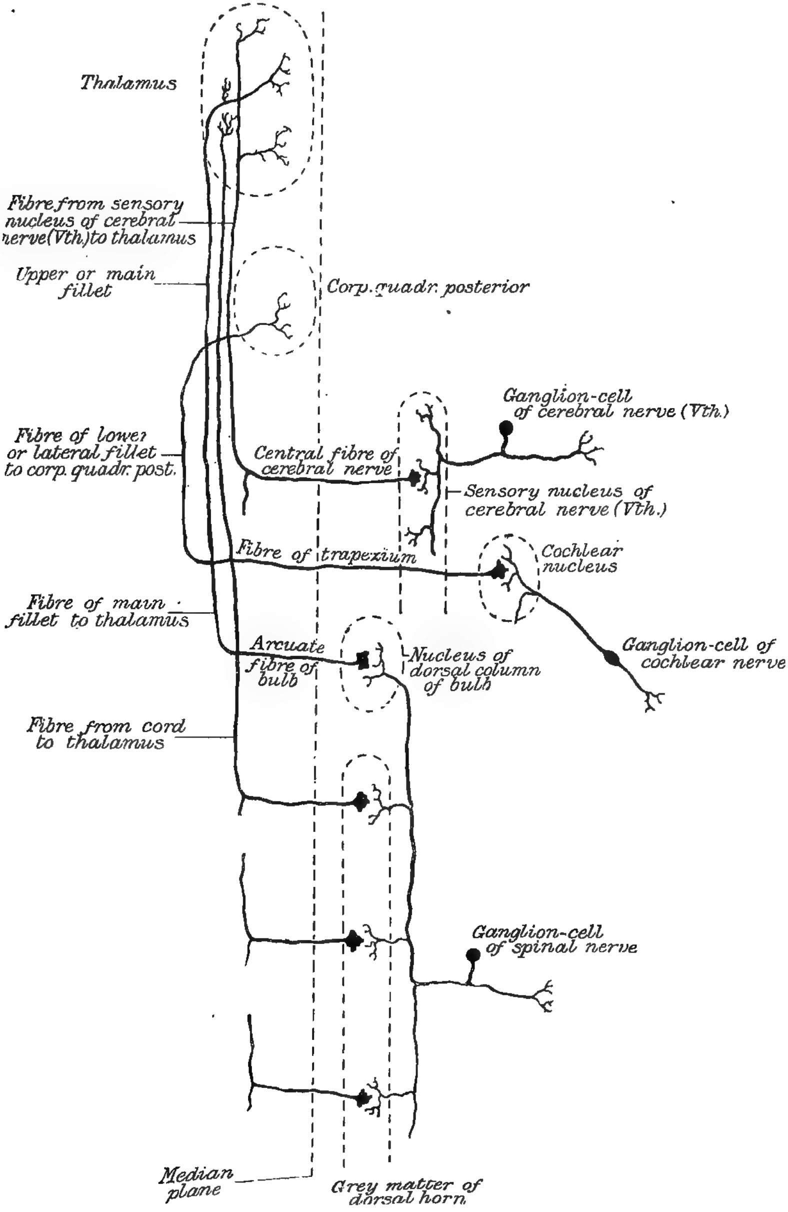
Thalamus
Fibre from sensory nucleus of cerebral nerve (Vth) to thalamus
Upper or main fillet
Corp. quadr. posterior
Ganglion-cell of cerebral nerve (Vth.)
Fibre of lower or lateral fillet to corp. quadr. post.
Central fibre of cerebral nerve
Sensory nucleus of cerebral nerve (Vth.)
Fibre of trapezium
Cochlear nucleus
Fibre of main fillet to thalamus
Arcuate fibre of bulb
Nucleus of dorsal column of bulb
Ganglion-cell of cochlear nerve
Fibre from cord to thalamus
Ganglion-cell of spinal nerve
Median plane
Grey matter of dorsal horn

FIG. 613.—DIAGRAM OF SENSORY PATH TO MID-BRAIN AND THALAMUS.

the dorsal longitudinal bundle, giving off collaterals to the oculo-motor nuclei and the nuclei of the fourth and sixth nerves as they descend. Its fibres eventually mix with those of the dorsal longitudinal bundle, and pass into the ventral column of the cord, joining the ventro-lateral descending tract (p. 424).

The *ponto-spinal lateral tract* is formed of fibres which arise from large cells of the reticular formation, and run down within the lateral area of this formation in the pons and medulla oblongata to reach the part of the lateral column of the cord which lies between the grey matter and the tracts of Monakow and Gowers. It is, however, mixed here with many fibres of different origin. The destination of its fibres is similar to those of the dorsal and ventral longitudinal bundles, viz.: the adjacent grey matter of the ventral horn.

The *vestibulo-spinal tract* is composed of fibres derived from the cells of the nuclei of Deiters and Bechterew, and is therefore similar in its origin to the fibres of the dorsal longitudinal bundle. The destination is in part also similar, for the fibres pass below into the ventral root zone of the cord and end in the grey matter of the ventral horn; but in their course downwards they lie in the lateral part of the medulla oblongata mixed up with those of Monakow's tract and the ponto-spinal tract, as well as with the ascending fibres of Gowers' tract.

The *central tract of the tegmentum* (Bechterew) runs in the pons exactly in the middle of the reticular formation of the tegmentum, but in the medulla oblongata it lies more ventrally near the olivary nucleus, beyond which it has not been traced. The origin of its fibres is not certainly known, but appears to be the thalamus; their destination is the olivary body of the same side (see p. 438, *thalamo-olivary tract*).

Ascending tracts in the pons and medulla oblongata—Tract of the fillet.—In the ventral part of the reticular formation is a very well-marked tract of fibres somewhat flattened dorso-ventrally in the pons; this is the *tract of the fillet.* Its fibres are partly derived from cells in the nuclei of the opposite fasciculus gracilis and fasciculus cuneatus of the medulla oblongata which have crossed the raphe as internal arcuate fibres; partly from cells in the nuclei which are connected with the terminations of the sensory cranial nerves.

In the mid-brain the fillet splits up into two distinct bundles of fibres termed respectively the *lateral* or *lower* and the *intermediate* or *upper fillet.* The fibres of the *lower fillet* are seen at the side of the mesencephalon (*fillet of Reil*), and are traceable partly to the grey matter of the inferior corpora quadrigemina (fig. 620), partly to the mesial geniculate body, in both of which they terminate; they are derived from the sensory nuclei of the medulla oblongata and pons (mainly from the acoustic nuclei). Those of the *upper fillet* go to the thalamus (fig. 625); they are chiefly the fibres from the cells of the opposite dorsal columns of the medulla oblongata (fig. 613).

Besides the ascending fibres of the tract of the fillet, this bundle includes a certain number of fibres which degenerate below a section of the tract and are therefore descending (centrifugal): their cells of origin appear to lie in the thalamus; these fibres are situated mesial to the true fillet of which they were formerly considered to be a part (being termed "mesial" fillet): they form a *thalamo-bulbar tract.* Mesial to the tract just mentioned is a bundle, also consisting of descending fibres, belonging to the system of the pyramid tract, and containing fibres which eventually come into relation with certain of the cranial motor nuclei (Hoche). This constitutes the *cortico-bulbar tract* (see p. 453). In the crusta it lies dorso-lateral to the other pyramid tract fibres.

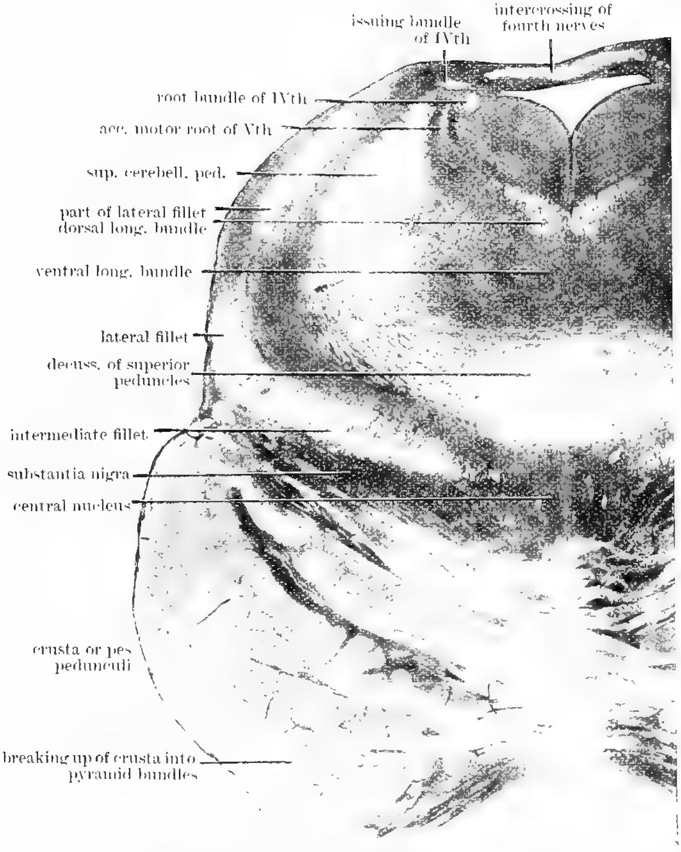

FIG. 614. TRANSVERSE SECTION THROUGH THE UPPER PART OF THE PONS. Photograph. Magnified about 3½ diameters.

Many of the fibres which continue the sensory path of the cranial nerves upwards lie in the formatio reticularis (tegmentum), somewhat dorsal to the tract of the fillet, forming a homologous but not clearly defined tract, which runs up through the pons and mid-brain to terminate in the subthalamic region and in the optic thalamus (*central tract of the sensory cranial nerves*). Another ascending tract is the special bundle of fibres from the sensory nucleus of the fifth to the thalamus previously referred to (p. 453).

At the *upper part of the pons* (fig. 614) the fourth ventricle narrows gradually towards the Sylvian aqueduct, and above on each side of it two considerable masses of longitudinal white fibres make their appearance. These are the *superior peduncles of the cerebellum.* They tend, as they pass forwards, gradually to approach the middle line; immediately below and in the region of the posterior colliculi of the corpora quadrigemina, they pass across this, decussating with one another, to enter the formatio reticularis of the opposite side.

The fibres of the superior cerebellar peduncles take origin in the cerebellum, emerging from its dentate nucleus, from the cells of which they are derived. They cross the raphe in the mid-brain and terminate in the red nucleus of the (opposite) tegmentum; but some of them give off a descending branch within the peduncle after crossing: its destination is not known.

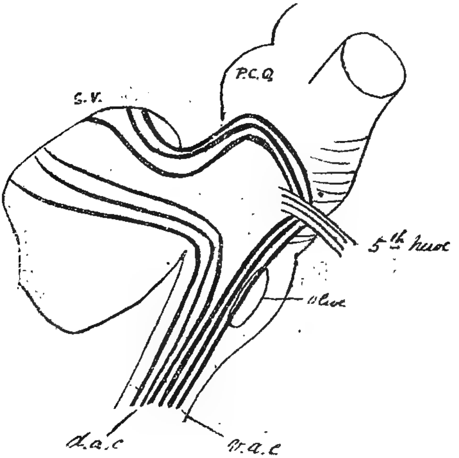

FIG. 615.—DIAGRAM TO SHOW THE MODE OF PASSAGE OF THE FIBRES OF THE DORSAL AND VENTRAL SPINO-CEREBELLAR TRACTS RESPECTIVELY INTO THE CEREBELLAR VERMIS. (F. W. Mott.)

p.c.q., posterior corpora quadrigemina; *s.v.*, superior vermis of cerebellum; *d.a.c.*, dorsal ascending cerebellar tract; *v.a.c.*, ventral ascending cerebellar tract.

The *ventro-lateral ascending tract* of the spinal cord (p. 426) is continued up in the lateral column of the medulla oblongata dorso-lateral to the olive and through the ventral part of the pons Varolii lateral to the pyramid bundles, but at about the level of the exit of the fifth nerve many of its fibres begin to pass obliquely towards the dorso-lateral part of the pons (fig. 615), where the superior cerebellar peduncle is emerging from the cerebellar hemisphere. The tract in question (*ventral spino-cerebellar tract*) now curves over the lateral aspect of this peduncle (fig. 616, *Tr. spino-cereb. ventr.*), and then takes a sharp backward turn, passing over the dorsal aspect of the peduncle to enter the middle lobe of the cerebellum in the superior medullary velum.

THE MID-BRAIN OR MESENCEPHALON.

In sections across the **mesencephalon** (figs. 618, 619, 621) the upward continuity of the parts which have already been described in the lower nerve-centres can still in great measure be traced.

The *Sylvian aqueduct* (fig. 619, *Sy*), with its lining of ciliated epithelium, represents the central canal of the cord and the fourth ventricle of the medulla oblongata. In the grey matter which surrounds it (*central grey matter*) there is seen in all sections of the region a group (column) of large nerve-cells (*oculomotor nucleus*) lying ventrally on each side of the middle line, close to the reticular formation. From the lowest cells of this column the root-bundles of the fourth nerve arise at the lower part of the mesencephalon and pass obliquely backwards and downwards around the central grey matter, decussating with those of the opposite side to emerge just above the pons Varolii (figs. 614, 617). Higher up, in the region of the anterior colliculi, the bundles of the third nerve spring from a continuation of the same nucleus (fig. 621, *n.III.*), and these pass forwards and downwards with a curved course through the reticular formation, to emerge at the mesial side of the crusta. According to Van Gehuchten, some of the fibres of the third nerve cross the middle line and emerge with the nerve of the opposite side.

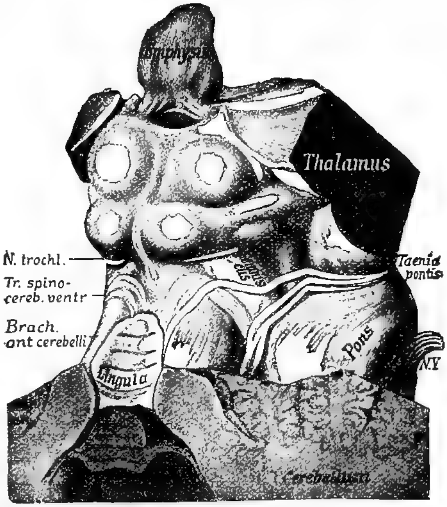

FIG. 616. THE CORPORA QUADRIGEMINA AND NEIGHBOURING PARTS OF THE BRAIN. (Edinger from G. Retzius.)

Brach. ant. cerebelli, the superior cerebellar peduncles, between them the anterior medullary velum partly covered by the lingula; *Tr. spino-cereb. ventr.*, tract of Gowers curving round the peduncle; *lemniscus*, the lateral fillet; *N. trochl.*, fourth nerve; *N.V.*, fifth nerve.

Tegmentum.—The reticular formation of the pons is continued up into the mesencephalon and is here known as the *tegmentum*. It is composed

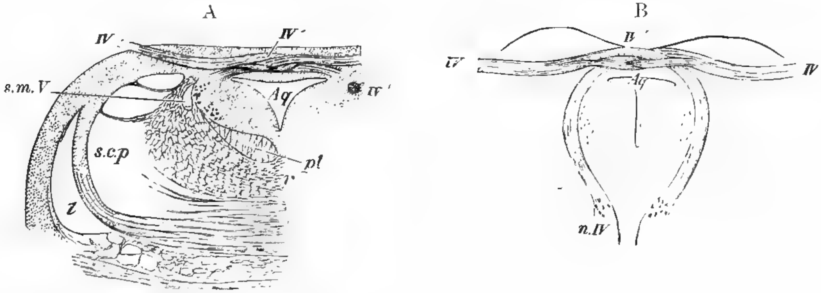

FIG. 617.—SECTION THROUGH THE ORIGIN OF THE FOURTH NERVE. (Schwalbe.)

A, transverse section at the place of emergence of the nerve-fibres. B, oblique section carried along the course of the bundles from the nucleus of origin to the place of emergence. *Aq*, Sylvian aqueduct, with its surrounding grey matter; *IV*, the nerve-bundles emerging; *IV'*, decussation of the nerves of the two sides; *IV''*, a bundle passing by the side of the aqueduct to emerge a little lower down; *n.IV*, nucleus of the fourth nerve; *l*, lateral fillet; *s.c.p.*, superior cerebellar peduncle; *s.m.V.*, superior motor root of the fifth nerve; *pl*, dorsal longitudinal bundle; *r*, raphe.

as before of longitudinal and transverse or arcuate bundles of fibres with much grey matter intermingled. The transverse fibres include the decussating fibres of the *superior peduncles of the cerebellum* (*s.c.p.*), which are derived from cells in the dentate nucleus of the cerebellum, and on reaching the opposite side bifurcate. Their ascending branches become gradually lost amongst a number of nerve-cells which collectively constitute what is known as the *red nucleus* or *nucleus of the tegmentum*, whilst the descending branches turn downwards in the reticular formation (Cajal) (see p. 458). But some of the fibres of the superior peduncle go on past the red nucleus to the ventral part of the thalamus. The red nucleus also receives fibres in its lateral aspect which are derived from the lenticular nucleus of the corpus striatum, and some of which are said to come from the cerebral cortex; these fibres form a sort of capsule to the red nucleus before entering it.

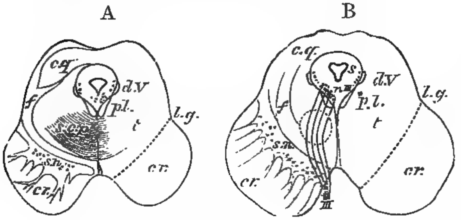

FIG. 618.—OUTLINE OF TWO SECTIONS ACROSS THE MESENCEPHALON. Natural size.

A, through the middle of the inferior corpora quadrigemina. B, through the region of the superior corpora quadrigemina. *cr.*, crusta; *s.n.*, substantia nigra; *t*, tegmentum; *s*, Sylvian aqueduct, with its surrounding grey matter; *c.q.*, grey matter of the corpora quadrigemina; *l.g.*, lateral groove; *p.l.*, dorsal longitudinal bundle; *d.V.*, superior root of the fifth nerve; *s.c.p.*, superior cerebellar peduncle; *f*, lateral fillet; *III.*, third nerve; *n.III.*, its nucleus. The dotted circle in B indicates the situation of the tegmental or red nucleus.

Tracts in the tegmentum.—1. *Vestibulo-motor tract; dorsal (posterior) longitudinal bundle.*—This is well marked in the mid-brain, and gives off many collaterals and terminal fibres to the oculomotor nucleus which is immediately dorsal to it. The bundle largely consists of nerve-fibres derived from the cells of Deiters' nucleus (see p. 446), which on reaching the situation of the bundle either on the same or on the opposite side, bifurcate, one branch ascending, the other descending. But it receives fibres from other sources than Deiters' nucleus, *e.g.*, from large cells of the sensory nucleus of the fifth, and from large cells in the reticular formation of the medulla oblongata, pons, and mid-brain. All these fibres, like those from Deiters' nucleus, bifurcate on joining the bundle, one branch passing upwards, the other downwards. Some fibres of the bundle are of different origin from the rest, arising beyond the oculomotor nucleus. These are very fine; they are descending fibres, and are traceable from the cells of the *nucleus of the dorsal longitudinal bundle*, which lies in front of the Sylvian aqueduct in the grey matter at the side of the third ventricle. Some of the fibres of the dorsal longitudinal bundle are traceable as far up as the thalamus.

The bundle gives collaterals not only to the oculomotor nucleus (fig. 620, *j*) but also to the nucleus of the sixth, and probably to the nuclei of other cranial motor nerves. Its descending fibres are eventually continued down the spinal cord in the ventro-lateral descending tract, and give off terminals and collaterals to the ventral horn.

2. *Rubro-spinal tract; Monakow's bundle.*—The cells of the red nucleus send their axons downwards and forwards. They form Monakow's bundle or the *rubro-spinal tract,* which is continued below into the *prepyramidal tract* of the spinal cord.

3. *Tecto-spinal tract; ventral longitudinal bundle.*—Other longitudinal fibres of the tegmentum are those of the *fasciculus retroflexus* of Meynert lying mesially to the red nucleus and passing obliquely downwards and inwards from the ganglion of the habenula to the interpeduncular ganglion of the opposite side, and the *bundle of Münzer,* which passes from the posterior tubercle downwards into the lateral part of the reticular formation of the pons. But the longest and most important is the *ventral* or *anterior longitudinal bundle,* which passes lateral to the red nucleus and partly through it. Although the red nucleus receives many collaterals from this bundle the fibres of the bundle are derived, according to Held and Cajal, from cells in the grey matter of the

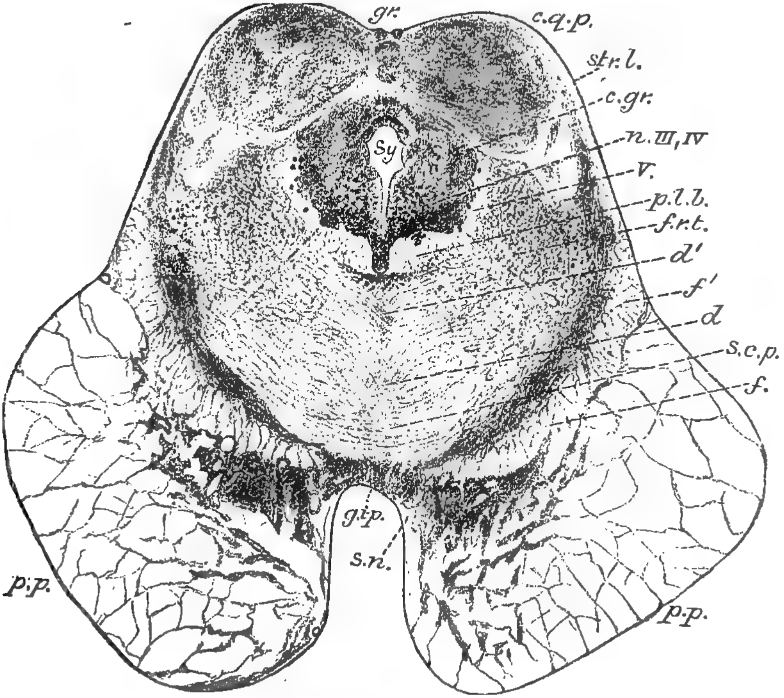

FIG. 619.—SECTION ACROSS THE MID-BRAIN THROUGH THE INFERIOR PAIR OF CORPORA QUADRIGEMINA. Magnified about 3½ diameters. From a photograph.

Sy, aqueduct of Sylvius; *c.gr.,* central grey matter of the aqueduct; *n.III.IV.,* group of cells forming part of the conjoined nucleus of the third and fourth nerves; *c.p.q.,* one of the posterior corpora quadrigemina; *gr,* median groove separating it from that of the opposite side; *str.l.,* stratum lemnisci (layer of the fillet), forming its superficial layer; *f,* upper fillet; *f',* lateral fillet; *V,* accessory motor root of fifth nerve; *p.l.b.,* dorsal longitudinal bundle; *f.r.t.,* formatio reticularis tegmenti; *d, d',* decussating fibres of tegmenta (fountain-decussations of Forel and Meynert); *s.c.p.,* superior cerebellar peduncles, decussating; *p,p.,* pes pedunculi (crusta); *s.n.,* substantia nigra; *g.i-p.,* interpeduncular ganglion.

opposite anterior tubercle of the corpora quadrigemina; these cells send their axons sweeping round the central grey matter just central to the dorsal longitudinal bundle to cross in the raphe, where they form the *fountain-like decussation of Meynert* (fig. 619, *d'*).[1] The downward continuation of the tecto-spinal tract has already been studied, but it should be stated that the prolongation of its fibres into the ventral column of the spinal cord is denied by Van Gehuchten, who traces them only as far as the medulla oblongata.

4. *Tract of the fillet.*—The continuation upwards of the fillet is also apparent in this part of the brain. Some of its fibres are seen passing in an oblique manner to the side of the mesencephalon, to enter the grey matter of the prominences of the posterior corpora quadrigemina.

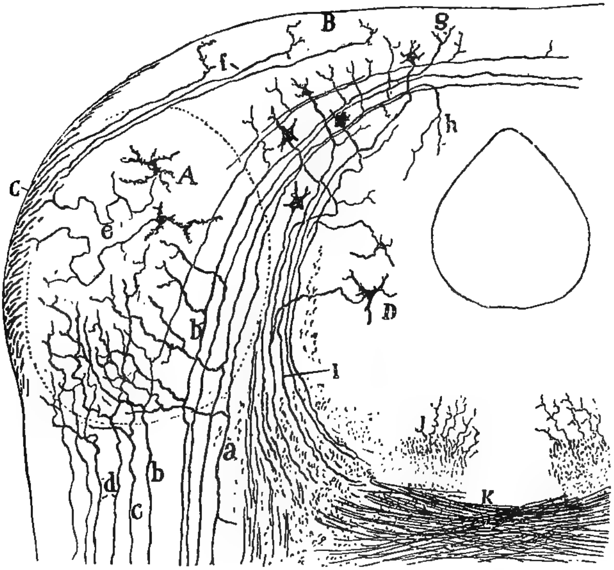

Fig. 620.—Diagram showing the general structure of the posterior corpora quadrigemina. (Cajal.)

A, principal mass of grey matter; B, C, cortical layer; D, grey matter around Sylvian aqueduct; K, decussation of superior peduncles of cerebellum; *a*, *b*, *c*, *d*, fibres of central acoustic path from lateral fillet; *e*, axons from cells of principal nucleus passing towards brachium; *f*, fibres from brachium passing into superficial layer; *g*, fibres from fillet passing into superficial layer; *h*, a fibre of fillet passing to central grey matter of aqueduct; *j*, collaterals from dorsal longitudinal bundle passing to oculo-motor nucleus; *l*, axons of cells in superomesial part of colliculus curving round grey matter of aqueduct and forming the deep white layer.

This part is the *lower* or *lateral fillet* (see p. 456), which is formed chiefly by fibres derived from the accessory auditory, the inferior olivary, and the trapezoid nuclei of the opposite side, forming the *central acoustic tract.* Its fibres send numerous collaterals to the posterior tubercle (fig. 620) and a few to the anterior, and end by ramifying amongst the cells of the mesial geniculate body (Cajal). In its course it traverses the *nucleus of the fillet.* This consists of cells interpolated amongst its fibres (the greater number in the lower part near the superior olive); amongst the cells some of the fibres and many collaterals from them end. The axons of the cells trend inwards towards the raphe. The *upper fillet* is continued upwards in the ventral part of the tegmentum towards the thalamus (p. 468).

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[1] This is not to be confounded with the *fountain-like decussation of Forel* (fig. 619, *d*), which lies nearer the ventral part of the tegmentum, and is partly formed by the intercrossing of Monakow's bundle and partly by v. Gudden's bundle coming from the corpora mammillaria to end in the tegmentum.

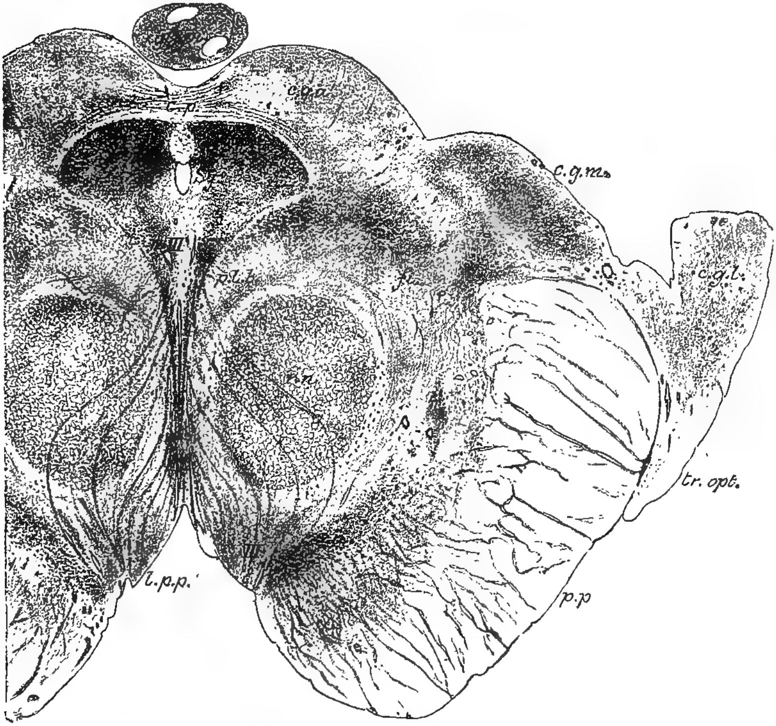

FIG. 621.—SECTION ACROSS THE MID-BRAIN THROUGH THE SUPERIOR CORPORA QUADRIGEMINA. Magnified about 3½ diameters. From a photograph.

c.p., posterior commissure of brain; *gl.pi.*, pineal gland; *c.q.a.*, grey matter of one of superior corpora quadrigemina; *c.g.m.*, mesial geniculate body; *c.g.l.*, lateral geniculate body; *tr.opt.*, optic tract; *p.p.*, crusta or pes pedunculi; *p.l.b.*, dorsal longitudinal bundle; *fi*, upper fillet; *r.n.*, red nucleus; *III.*, issuing fibres of third nerve; *n.III.*, its nucleus; *l.p.p.*, locus perforatus posticus; *Sy*, Sylvian aqueduct.

Crusta.—Lateral and ventral to the tegmentum is seen on either side the white mass known as the *crusta* or *pes pedunculi* (fig. 618, *cr.*; figs 619, 621, *p.p.*). This is formed by longitudinally coursing bundles of fibres lying on the ventral aspect of each half of the mesencephalon, and diverging above into the internal capsule of the cerebral hemisphere.

The fibres of the crusta are continued below into the so-called "pyramid bundles" of the pons—which contain, as we have seen, many other fibres than those of the pyramid tract. This is also the case with the bundles of the crusta, in which the pyramid tract proper—composed of fibres emanating from the precentral and paracentral gyri—is confined to the middle three fifths (which, however, includes many cortico-pontine fibres), whilst the mesial fifth is mainly occupied by fibres passing from the lower frontal region to the pons, carrying impulses to the nuclei of the facial and hypoglossal; and the lateral fifth by fibres the origin and function of which are not certainly known. But it is probable that these last fibres are connected with the regions of the hemisphere behind the Rolandic fissure, especially, perhaps, with the temporal and occipital regions; and are passing from the pyramidal cells of those parts to end in the nuclei of the pons.

Substantia nigra.—The crusta is separated from the tegmentum by a layer of grey matter containing a number of very deeply pigmented nerve-cells (*substantia nigra*; figs. 619, 621, *s.n.*). The substantia nigra receives many collaterals from the adjacent pyramid bundles of the crusta (Sutherland Simpson). The crusta and tegmentum, together with the intervening substantia nigra, constitute the *cerebral peduncle* or *crus cerebri.*

Interpeduncular ganglion.—Between the cerebral peduncles, just where they diverge from the mass of transverse fibres of the pons, is seen close to the ventral surface of the brain a small mass of grey matter containing a large number of small nerve-cells with large and irregular dendrons, and axons which are directed dorsally into the tegmentum. This is the *interpeduncular ganglion* (fig. 619, *g.i-p.*). It receives on each side the ending of the *fasciculus retroflexus* of Meynert which comes from the *ganglion of the habenula*, a collection of nerve-cells near the superior and mesial part of the thalamus, close to the commencement of the third ventricle. These ganglia are both much better marked in many of the lower animals than in man.

Corpora quadrigemina.—The prominences (*colliculi* or *tubercles*) of the corpora quadrigemina are formed mainly of grey matter. Connected laterally with each is a bundle of white fibres forming the *brachia* of the geniculate bodies.

The **posterior or inferior colliculi** consist of a *grey centre* which is enclosed by *superficial* and *deep white layers* (figs. 619, 620). The superficial white layer is derived mainly from the brachium. The fibres of the fillet divide as they approach the colliculus; one branch enters its grey matter while the other passes to the mesial geniculate body. In animals with a highly developed sense of hearing all these parts are proportionately well-developed. The deep white layer is derived from cells of the grey centre, but many of the cells of the latter send their axons towards the superficial layer. The destination of the fibres of the deep white layer is not certainly known; some pass over the central grey matter of the aqueduct to the opposite side.

In the **anterior or superior colliculi** four layers can be distinguished (fig. 622), viz.: superficially, a *thin white layer* (A), containing nerve-fibres and a few nerve-cells disposed parallel to the surface; next to this a *grey cap* (B), containing many and various nerve-cells, amongst which the terminations of the optic nerve (*h*, *h*) ramify; below this the *optic nerve layer* (C), which is formed of antero-posteriorly running fibres derived from the optic tract, and ending as just stated for the most part in the grey layer. The optic nerve layer also contains some nerve-cells. Lastly there is a deep white layer, the so-called *deep medulla*, of transversely disposed fibres (D) derived partly from the fillet, but comprising many fibres which come from the cells of the colliculus itself, and a few which are continued up from the ventro-lateral column of the spinal cord. This deep layer also contains a number of large dendritic cells amongst the fibres. The superior corpora quadrigemina receive through their brachia many of the fibres of the optic tracts, which in mammals enter the grey matter at the middle of its thickness and traverse it from before back, so that in transverse sections of the mid-brain they appear cut across. In birds they form a superficial white stratum covering the grey matter; this white stratum is not homologous with the superficial stratum of mammals, for the fibres in the latter are not derived directly from the optic tract. The optic fibres are all derived from nerve-cells in the retina, and as they traverse the stratum opticum they pass obliquely into the grey matter (in a ventral direction in birds, in a dorsal direction in mammals) and end in arborisations amongst its cells. The cells of the grey matter are very various in form and size (fig. 622). Most of their axis-cylinder processes pass ventralwards. The destination of all is not certainly known, but some form the commencement of the ventral longitudinal bundle of the opposite side, and others run

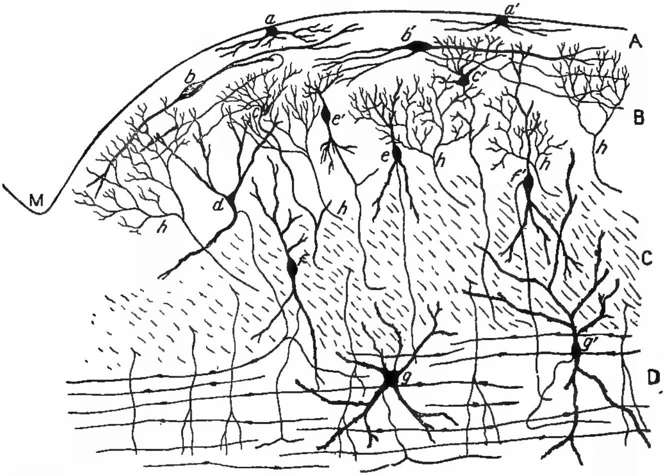

FIG. 622.—DIAGRAM SHOWING THE CHARACTERS OF THE CELLS IN THE GREY MATTER OF THE ANTERIOR CORPORA QUADRIGEMINA. (After Cajal.)

M, portion of dorsal median groove; A, superficial white layer; B, grey cap; C, optic fibre layer (upper grey-white layer); D, layer of the fillet (lower grey-white layer).

a, *a'*, marginal nerve-cells; their axons are not represented; *b*, *b'*, horizontal spindle-shaped cells of Golgi's type II.; *c*, *c'*, small cells with much branched dendrons and an axon extending to the optic fibre layer; *d*, *e*, *e'*, spindle and stellate cells of the grey cap, and *f*, *f'*, cells of the stratum opticum, sending their axons into the layer of the fillet; *g*, *g'*, cells of the layer of the fillet; *h*, *h*, fibres of the optic nerve layer ending in the grey and superficial white layers.

down on the same side towards the pons Varolii, intermingled with the ascending fibres of the fillet. A certain number of fibres which take origin in the cells of the anterior colliculi course over the central grey matter which surrounds the Sylvian aqueduct and sweep round this towards the fillet-tract of the opposite side. These *commissural fibres* are continuous in front with those of the posterior commissure.

The nerve-fibres of the optic nerve and optic tract do not all enter the corpora quadrigemina. Many, indeed the majority, pass into the lateral geniculate bodies and optic thalami to form arborisations there (fig. 627). On the other hand, axons from the cells of these structures pass to the cortex of the brain (occipital region).

As has just been stated, many arcuate fibres issue from the grey matter of the corpora quadrigemina and pass obliquely downwards into the ventral part of the mesencephalon encircling the central grey matter. These fibres intercross in the raphe, where they constitute the fountain-decussation of Meynert (p. 462), and after crossing constitute the main mass of the ventral longitudinal bundles. These are continued into the ventral columns of the spinal cord; they give off collaterals to the motor nuclei of the eye-muscles, and probably to the motor nuclei generally. Other fibres which appear to belong to the same (*tecto-spinal*) system are traceable as a distinct tract into the lateral column of the cord (see p. 424).

In the cat, the anterior corpora quadrigemina receive a number of fibres from the pyramid tract in the crusta of the same side, a few crossing over the aqueduct to the opposite colliculus (Boyce, Sutherland Simpson). But in most animals the fibres which pass from the cortex cerebri to the corpora quadrigemina enter these bodies through their respective brachia.

No fibres are given off from the cells of the corpora quadrigemina to the cortex cerebri.

Posterior commissure.—Immediately in front of the corpora quadrigemina, visible in the roof of this part of the mid-brain, is the *posterior commissure.* This consists of fibres which arise in a nucleus at each side of the Sylvian aqueduct and which pass across the middle line dorsal to the central grey matter and then turn ventralwards and caudalwards to pass down in the tegmentum lateral to the dorsal longitudinal bundle, which is partly reinforced by the fibres in question. Fibres of the posterior commissure extend into the region of the third ventricle.

The optic nerves.—The only sensory nerves which are immediately connected with the mid-brain are the *second* or *optic.* Their origin is from the large nerve-cells of the ganglion of the retina. The nerve leaves the globe of the eye at its posterior aspect, passes through the optic foramen to the base of the brain, and joins the nerve of the opposite side to form the *optic chiasma* (fig. 627). Of the fibres which enter the chiasma, those from the inner (or nasal) two-thirds of the retina cross to the optic tract of the opposite side, while the remaining third, comprising the fibres from the temporal part of the retina, pass along the lateral border of the chiasma to the tract of the same side. In the optic tract they are continued to the parts of the brain where they have their terminal arborescences, viz., the external geniculate body and the adjoining posterior part of the thalamus (pulvinar) and the anterior corpora quadrigemina. A certain number of the fibres of the optic nerve bifurcate on reaching the chiasma, and the branches pass one into each optic tract (Cajal).

The fibres which pass to the anterior corpora quadrigemina are much finer than those to the corpora geniculata. It is probable that the former furnish the path for reflex movements of the pupil, etc., and the latter the path for visual impressions, since the lateral corpus geniculatum and pulvinar thalami are directly connected with the visual cortex in the occipital lobe, while, as already stated, no such direct connexion obtains between that cortex and the anterior corpora quadrigemina.

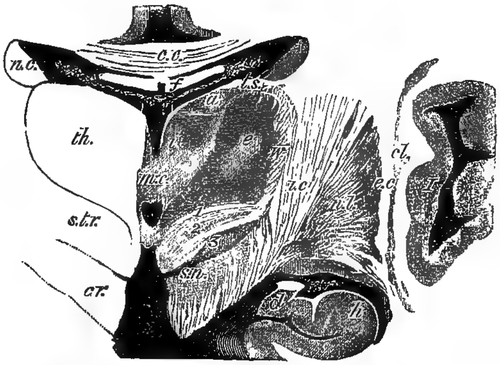

Fig. 623.—Transverse section through the cerebrum in the region of the middle commissure. Natural size.

c.c., corpus callosum; *f*, fornix; *n.c.*, nucleus caudatus; *th*, thalamus; *s.t.r.*, subthalamic region; *cr*, crusta passing into internal capsule; *s.n.*, substantia nigra; *a*, *e*, *i*, various nuclei of thalamus; *a*, its latticed layer; *1*, *2*, *3*, parts of subthalamus; *n.l.*, nucleus lenticularis; *e.c.*, external capsule; *cl.*, claustrum; *I*, insula; *m.c.*, middle commissure; above and below it is the third ventricle, communicating above on each side through the foramen of Monro with the lateral ventricle. Below the fornix are seen the choroid plexuses; *t.s.*, stria terminalis.

A small bundle of fibres (*transverse peduncular bundle*) leaves the optic tract as it enters the mid-brain and passes round the cerebral peduncle to lose itself in the mesial part of the tegmentum near the fillet. Its destination appears to be a small nucleus situated near the red nucleus. Its fibres degenerate after enucleation of the opposite eyeball.

The optic tracts and chiasma also contain the fibres of *v. Gudden's commissure*, which connects the posterior corpora quadrigemina; these fibres appear to have no relation to the visual function.

There are present in the optic nerve and tract a few fibres which originate in the nerve centres—where is not known—and terminate in the retina.

Motor nerves.—The motor nerves arising from the mid-brain are the third and fourth. The position of their nuclei and their mode of exit have been already described (p. 459).

THE THALAMENCEPHALON.

The **thalamus** (figs. 623, 624, *th.*), which lies at the side of the third ventricle and forms part of the floor of the lateral ventricle, is covered on its free surface by a layer of white fibres. Laterally it is bounded by the internal capsule. Fibres from the latter pass into the thalamus and serve to connect it with the hemisphere.

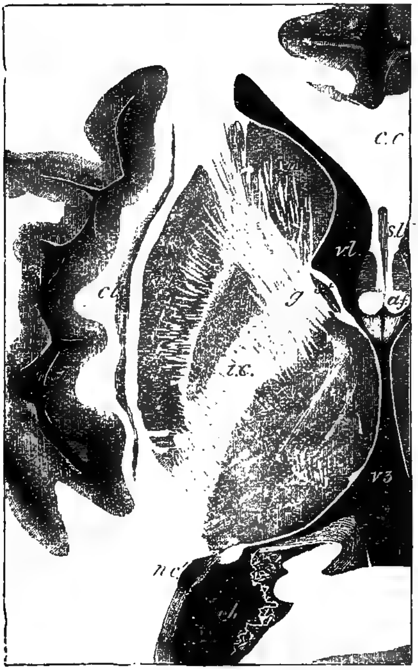

FIG. 624.—HORIZONTAL SECTION THROUGH THE OPTIC THALAMUS AND CORPUS STRIATUM. Natural size.

v.l., lateral ventricle, its anterior cornu; *c.c.*, corpus callosum; *s.l.*, septum lucidum; *a.f.*, anterior pillars of the fornix; *v3*, third ventricle; *th.*, thalamus opticus; *st.*, stria medullaris; *nc.*, *nc'.*, nucleus caudatus, and *nl.*, nucleus lenticularis of the corpus striatum; *i.c.*, internal capsule; *g*, its angle or genu; *nc'.*, tail of the nucleus caudatus appearing in the descending cornu of the lateral ventricle; *cl.*, claustrum; *I*, insula.

The grey matter of the thalamus is partially subdivided (fig. 623) by an oblique white lamina into a smaller *mesial nucleus*; and a larger *lateral nucleus*; these contain a large number of small nerve-cells. Anteriorly another portion of grey matter (*anterior nucleus*) is divided off in a similar way; this contains comparatively large nerve-cells. All these nuclei are formed of groups of cells having different connexions, many of which still require elucidation.

The thalamus receives the terminal branches of the fibres of the *upper fillet*, continued from the cells of the opposite nuclei of Goll and Burdach (spino-thalamic tract), those of the *central path of the fifth cranial nerve* of the opposite side, and some fibres from the *superior cerebellar peduncle* of the opposite side; besides the fibres of the *optic tract* which pass to the external geniculate body and pulvinar thalami.

From the cells of the thalamus nerve-fibres pass in every direction into the white matter of the hemisphere, and eventually to the cortex. From the outer part they tend especially towards the occipital region, assisting to form the *central visual tract* which passes to the visual cortex. From the inner and deeper part they converge towards the subthalamic region. Here many are collected into the ansa lenticularis (see p. 472), by which they pass into the nucleus lenticularis, while others, as already stated, enter the corona radiata and thus reach the cortex of the hemisphere. These fibres from the thalamus to the cortex probably form the third and the last link in the chain of sensory neurones, the second being formed by the neurones of the fillet and the first by the neurones of the sensory roots. On the other hand, the thalamus receives fibres both from the cortex and from the corpus striatum, to end amongst its cells.

Corpora geniculata.—Attached to the thalamus below and behind are the *geniculate bodies* (fig. 626). These at first sight appear to be both connected with the optic tract, but only the lateral one actually receives optic fibres, the mesial body receiving fibres from the central auditory tract through the lateral fillet. Of the geniculate bodies the *outer or lateral* has a lamellated structure consisting of alternating layers of grey and white matter, the white layers being composed partly of the entering optic fibres and partly of fibres emerging from the grey matter and passing to the central optic path, while the grey substance contains very numerous nerve-cells amongst which the fibres of the optic tract end in complex arborisations. From these cells axons arise and join a bundle of fibres which enters the white matter of the hemisphere above and along with the internal capsule, and passes to the visual area of the cortex (*central*

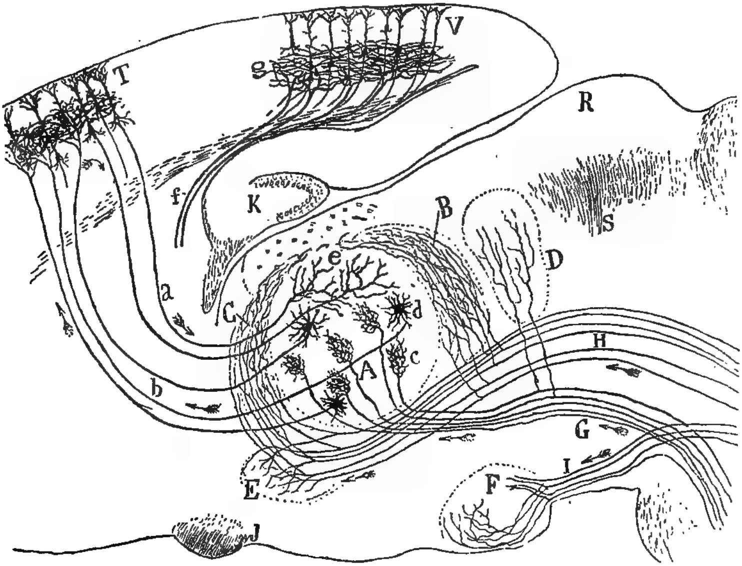

FIG. 625.—DIAGRAM OF THE CONNEXIONS OF THE THALAMUS WITH THE ASCENDING FIBRES OF THE FIFTH NERVE, AND OF THE UPPER FILLET ON THE ONE HAND, AND WITH THE CORTEX CEREBRI ON THE OTHER. (Cajal.)

A, B, C, D, E, various nuclei in thalamus; I, afferent fibres passing to mammillary body, F; G, tract of upper fillet ending in A (at *c*), and giving collaterals to D (posterior nucleus); H, central tract from sensory nucleus of fifth; T, cortex cerebri; V, visual cortex; R, anterior colliculus; J, optic chiasma; S, optic fibres; K, hippocampus.

a, fibres from cortex to thalamus, ending at *e*; *b*, fibres from cells in thalamus (*d*) to cortex; *f*, fibres from lateral geniculate body and thalamus to visual cortex, ending at *g* in stria of Gennari.

visual tract). Some of the fibres from the corpus geniculatum laterale, as they enter the visual tract, send branches downwards towards the tegmentum.

The cells of the *mesial geniculate body* are collected into two main nuclei, dorsal and ventral. Most of the cells are small, but at one part there is a group of large cells. The axons appear to pass through the brachium and eventually to the cortex: probably to that of the temporal lobe.

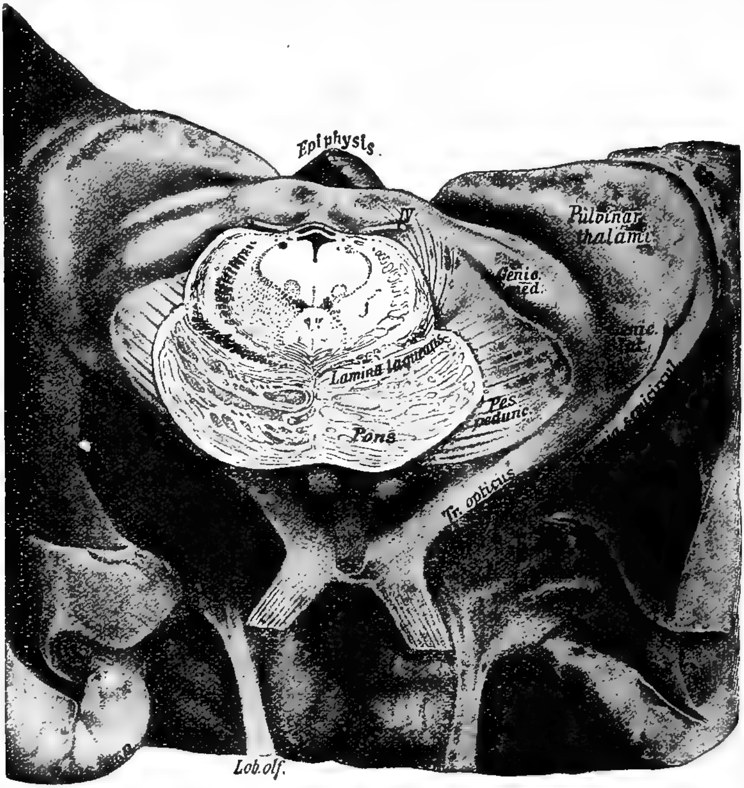

FIG. 626. — FIGURE SHOWING THE OLFACTORY TRACTS AND THEIR ROOTS: THE OPTIC CHIASMA AND OPTIC TRACTS: THE GENICULATE BODIES AND THE PULVINAR THALAMI. (Edinger.)

The pons is cut through at the anterior part, and the section shows the Sylvian aqueduct, the fillet (*lamina laquearis*), superior cerebellar peduncles, etc. The corpora mammillaria are partly concealed by the pons; between and in front of them is seen the infundibulum.

The **ganglion of the habenula** (fig. 628, *g*′) is a collection of nerve-cells which lies at the posterior part of the thalamus on each side, near the roof of the third ventricle. This ganglion receives on the one hand the fibres of the *habenula* or *stria medullaris*, and on the other hand gives off from its cells the fibres which form the *fasciculus retroflexus* or *Meynert's bundle* (fig. 654), passing downwards to the interpeduncular ganglion (p. 464). The two ganglia of the habenulæ are joined by a white commissure.

The **corpora mammillaria** (fig. 626) are seen at the base of the brain immediately below the posterior part of the third ventricle. Each is composed of white matter externally and grey matter internally. It receives fibres from the anterior pillar of the fornix of the same side; these fibres arise from cells in the hippocampus and end in the mammillary body. According to Edinger some fibres from the olfactory tract pass directly to it.

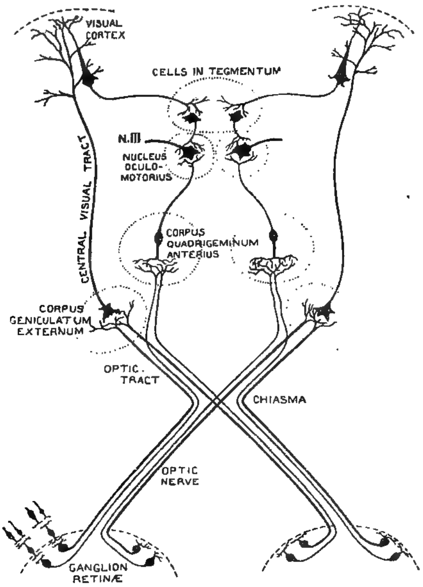

FIG. 627.—DIAGRAM TO SHOW THE PROBABLE COURSE AND RELATIONS OF THE OPTIC FIBRES.

Only single fibres are shown emerging from the anterior quadrigeminal and external geniculate bodies, continuing the course of the two fibres from corresponding points in the retinæ. This is merely to simplify the diagram, and is not intended to imply that the retinal impressions are fused in those situations.

The axons of its cells bifurcate; one branch, the coarser, passing into the anterior and upper part of the thalamus in the bundle of Vicq d'Azyr, and the other into the tegmentum of the mid-brain in v. Gudden's bundle. The corpora mammillaria form part of the central olfactory apparatus (fig. 654).

Subthalamic region.—The tegmentum of the crus cerebri is prolonged below the thalamus, and between it and the internal capsule is represented by a mass of grey substance, with longitudinally and obliquely crossing white bundles, which is known under the name of *subthalamus* or *hypothalamus* (fig. 628). Its deepest part contains a lens-shaped mass of grey matter prolonged forwards from the substantia nigra known as the *corpus subthalamicum* of Luys. A mass of fibres sweeps round this and round the internal capsule, passing between the thalamus and the nucleus lenticularis; the terms *zona incerta* and *ansa lenticularis* are employed to denote some of these strands, but their origin and destination have not been definitely ascertained.

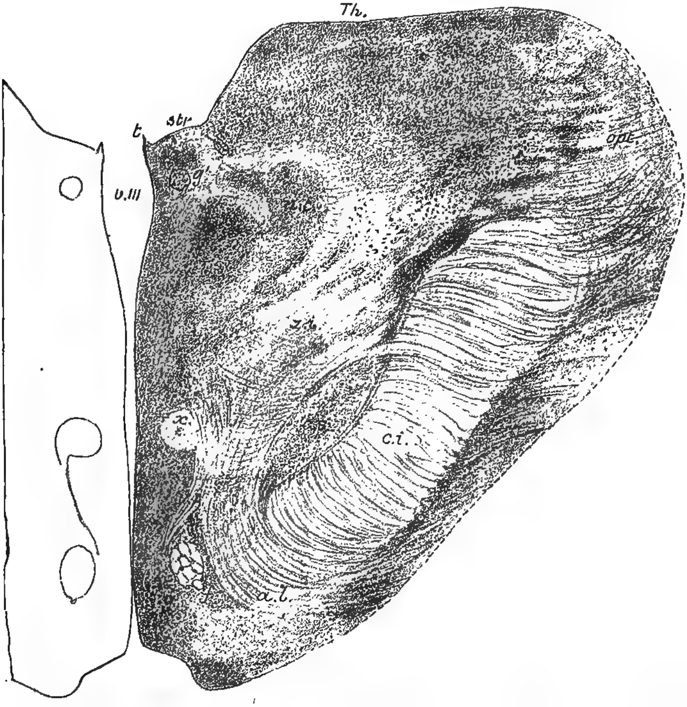

FIG. 628.—SECTION TAKEN OBLIQUELY THROUGH THE THALAMUS AND INTERNAL CAPSULE SHOWING SOME OF THE STRANDS OF FIBRES OF THE SUBTHALAMUS. Magnified 2½ diameters. From a photograph.

Th., thalamus; *v.iii.*, third ventricle; *t.*, tænia, or attachment of epithelial roof of ventricle; *str.*, stria medullaris or habenula; *g'*, ganglion of the habenula; *n.t.*, mesial nucleus of thalamus; *opt.*, optic fibres passing into pulvinar of thalamus; *z.i.*, zona incerta, from which fibres are seen emerging and sweeping as the *ansa lenticularis*, *a.l.*, round the internal capsule, *c.i.*, to pass toward the lenticular nucleus; *c.s.*, corpus subthalamicum; *f.*, anterior pillar of fornix passing backwards to corpus mammillare; *V.A.*, bundle of Vicq d'Azyr, passing upwards and forwards from corpus mammillare into thalamus; *g*, group of nerve-cells, probably belonging to the nucleus of the corpus mammillare; *x*, fasciculus retroflexus.

LESSONS XLIV. AND XLV.

STRUCTURE OF THE CEREBELLUM AND CEREBRUM.

1. Sections of the cerebellum vertical to the surface, (*a*) across the direction of the laminæ, (*b*) parallel with the laminæ.

2. Sections across the whole of one hemisphere of the cerebrum of a monkey or cat passing through the third ventricle.

3. Vertical sections of the cerebral cortex :—one across the central gyri, another from the occipital lobe (calcarine region), another across the superior temporal gyrus and island of Reil, and one across the hippocampal gyrus and hippocampus.

4. Transverse sections of the olfactory tract and bulb.

In all these preparations make sketches under a low power of the general arrangement of the grey and white matter, and also of the nerve-cells in the grey matter. Sketch some of the details under a high power.

The preparations are made in the same way as those of the spinal cord. Other preparations may be made by the Golgi method to exhibit the relation of the cells to one another. Such preparations may have been already partly studied (Lessons XVII. and XVIII.).

THE CEREBELLUM.

The **cerebellum** is composed of a white centre and a grey cortex (fig. 629). Both extend into all the folds or laminæ, so that when the laminæ are

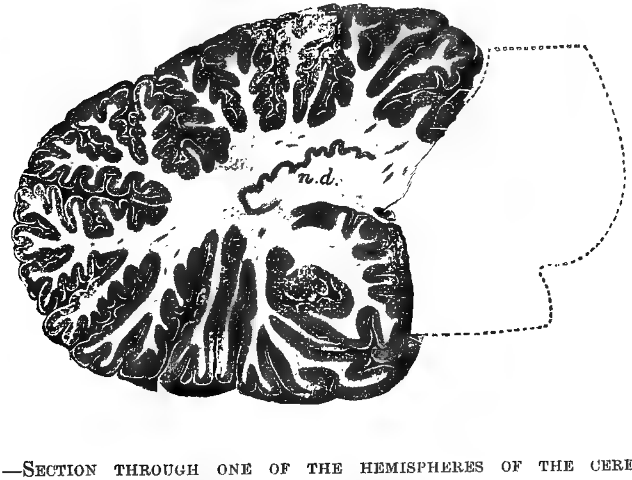

Fig. 629.—Section through one of the hemispheres of the cerebellum, showing the laminated arborescent appearance of the grey matter at the surface and the nucleus dentatis (*n.d.*) in the middle of the white centre. The pons is indicated by a dotted outline.

cut across, an appearance is presented of a white arborescence covered superficially by grey matter. The white matter is in largest amount in the middle of each cerebellar hemisphere. There is here present a peculiar wavy lamina of grey matter, similar to that in the olivary body, and known as the *nucleus dentatus* (fig. 629, *n.d.*). This receives numerous nerve-fibres from the cells of Purkinje of the cortex, which end by arborising around its cells. The latter give off axons which become the fibres of the superior cerebellar peduncles, and for the most part end in the opposite red nucleus (p. 460), but some pass beyond this into the subthalamic region. The dentate nucleus also receives collaterals from fibres of the inferior peduncle (Cajal).

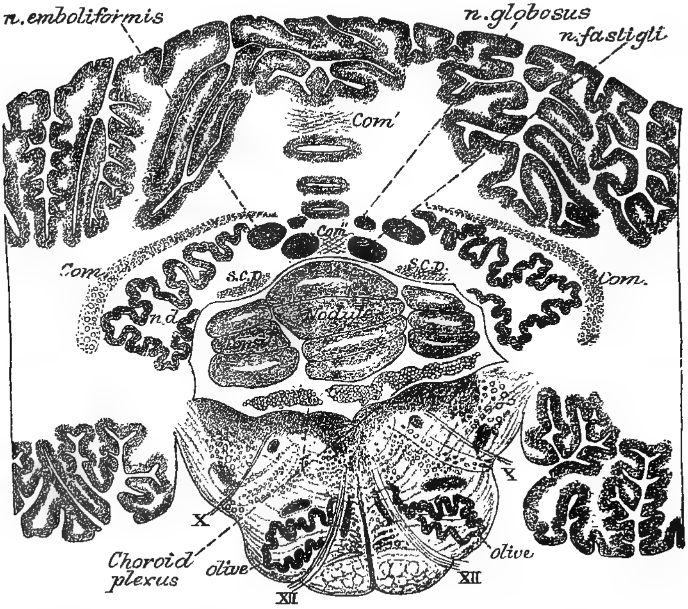

FIG. 630.—SECTION ACROSS THE CEREBELLUM AND MEDULLA OBLONGATA SHOWING THE POSITION OF THE NUCLEI IN THE WHITE CENTRE OF THE CEREBELLUM. (Stilling.)

n.d., nucleus dentatus cerebelli; *s.c.p.*, fibres of superior peduncle; *com*, *com'*, *com''*, commissural fibres; *X*, root-fibres of vagus; *XII*, root-fibres of hypoglossal nerve.

Other isolated grey nuclei lie in the white matter of the middle lobe over the roof of the fourth ventricle and constitute collectively the *nuclei of Stilling*. The most important of these appears to be the *nucleus tecti* (*s. fastigii*) (fig. 630). This receives many of the ascending fibres of the vestibular nerve (p. 446) and collaterals from the spino-cerebellar tracts, and gives origin to a bundle of fibres which crosses to the opposite side and descends in the mesial part of the restiform body to the reticular formation of the medulla oblongata (Risien Russell).

The **grey matter** of the cerebellum appears of essentially similar structure throughout the whole extent of the cortex. It consists of two layers. The *inner* or *granule layer* (fig. 631, *d*, and fig. 633, *B*) lies next to the white centre, and is composed of a large number of very small nerve-cells intermingled with a few larger ones and some neuroglia-cells. The *outer* or molecular layer (fig. 631, *b*, and fig. 633, *A*) is thicker, and is formed chiefly of fine nerve-fibres with small nerve-cells scattered through it. Into its outer part processes of the pia mater conveying blood-vessels pass vertically. Lying between the two layers of the grey matter is an incomplete stratum of large flask-shaped cells, termed the *cells of Purkinje* (fig. 631, *c*; fig. 632, fig. 633, *a*). Each of these cells gives off from its base a fine process (axon), which becomes the axis-cylinder of one of the medullated fibres of the white centre, while from the opposite pole of the cell large ramified processes (dendrons) extend into the superficial layer of the grey matter.

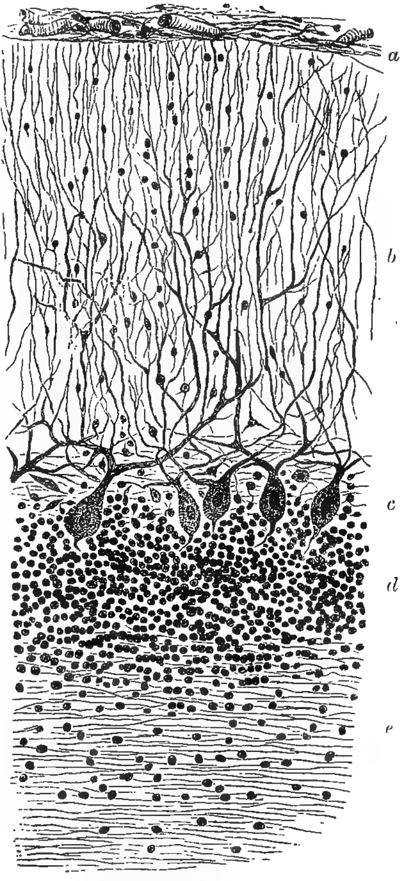

FIG. 631.—SECTION OF CORTEX OF CEREBELLUM. (Sankey.)

a, pia mater; *b*, outer or molecular layer; *c*, corpuscles of Purkinje; *d*, inner or granule layer; *e*, medullary centre.

The dendrons of the cells of Purkinje spread out in planes transverse to the direction of the lamellæ of the ogran, so that they present a different appearance according to whether the section is taken along a lamella or across it (compare fig. 633, I and II). These dendrons are invested at their attachment to the cell and, for some extent along their branchings, by a basket-work formed by the terminal arborisations of certain fibres (*climbing or tendril fibres*) of the medullary centre (fig. 635; fig. 636, *cl.f.*). The body of the cell of Purkinje is further invested by a felt-work of fibrils formed by the arborisation of axis-cylinder processes of nerve-cells (*basket-cells*) in the outer layer of the grey matter (figs. 634; 636, *b*). Each cell has therefore a double investment of this nature, one covering the dendrons, the other investing the body of the cell and extending along the commencement of the axon.

The *granules of the inner layer* of grey matter are mostly small nerve-cells, each with a few dendrons penetrating amongst the other granules, and an axon which is directed between the cells of Purkinje into the outer layer. After penetrating a variable distance into this layer the axon bifurcates, and its two branches pass in opposite directions at right angles to the main stem, and parallel to the direction of the lamella (fig. 633, I). What ultimately becomes of the branches is not known. In sections cut across the lamella the cut ends of these fibres give a finely punctated appearance to the outer layer (fig. 633, II).

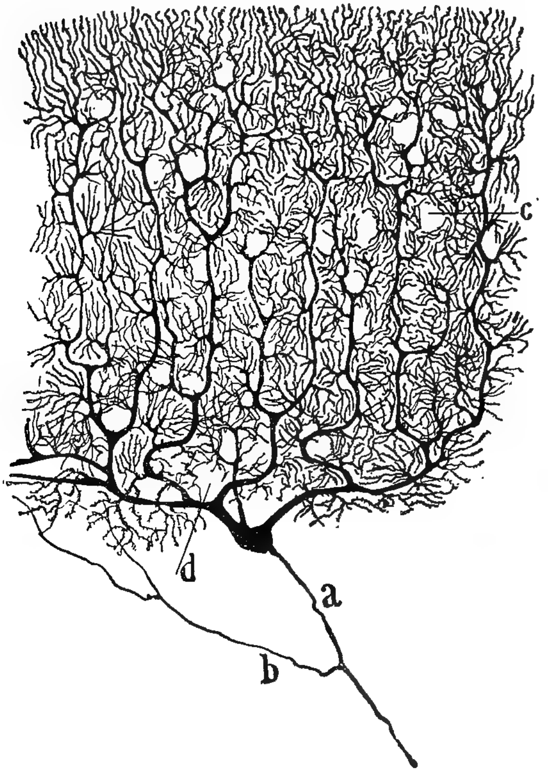

Fig. 632.—A cell of Purkinje of the cerebellum, shown by Golgi's method. (Cajal.)

a, axon ; *b*, collateral from axon ; *c*, *d*, arborisation of dendrons.

Some of the cells of the granule layer are far larger than the others, and send their much-branching axons amongst the smaller granules (*cells of Golgi*, fig. 636, G). Besides these, certain other large "granules" have been noticed by Cajal, occurring both in the granule layer and in the white centre, with long axons passing into the white matter of the cerebellum. These are comparatively few in number.

Ramifying amongst the cells of the granule layer are peculiar fibres derived from the white centre, and characterised by having pencils of fine short branches at intervals like tufts of moss (fig. 636, *m.f.*). These have been termed by Cajal the *moss-fibres*; they end partly in the granule layer, partly in the molecular layer.

The **neuroglia** of the cerebellum is peculiar in containing, besides the ordinary branched and unbranched neuroglia-cells (fig. 636, gl^1, gl^2), other large cells with long parallel processes which extend through the molecular layer to be attached to the surface of the lamellæ (gl^3). The cell-bodies lie at about the same level as those of Purkinje's cells.

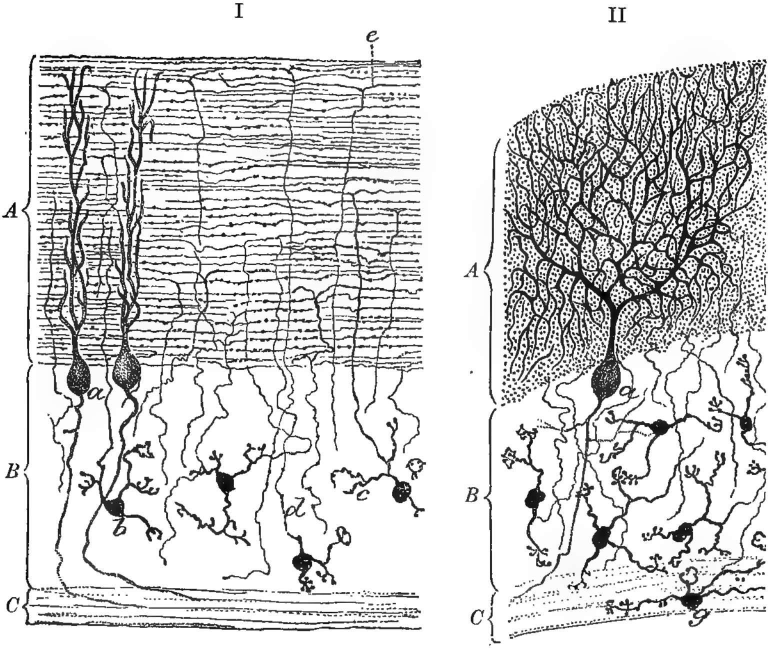

Fig. 633.—Sections of cortex cerebelli stained by Golgi's method. (Cajal.)

I.—Section made in the direction of a lamina. II.—Section taken across a lamina.

A, outer or molecular layer ; *B*, inner or granule layer ; *C*, medullary centre.

a, corpuscles of Purkinje ; *b*, small granules of inner layer ; *c*, a protoplasmic process (dendron) of a granule ; *d*, nerve-fibre process of a granule passing into the molecular layer, where it bifurcates and becomes a longitudinal fibre (in II these longitudinal fibres are cut across and appear as dots) ; *e*, bifurcation of another fibre ; *g*, a granule lying in the white centre.

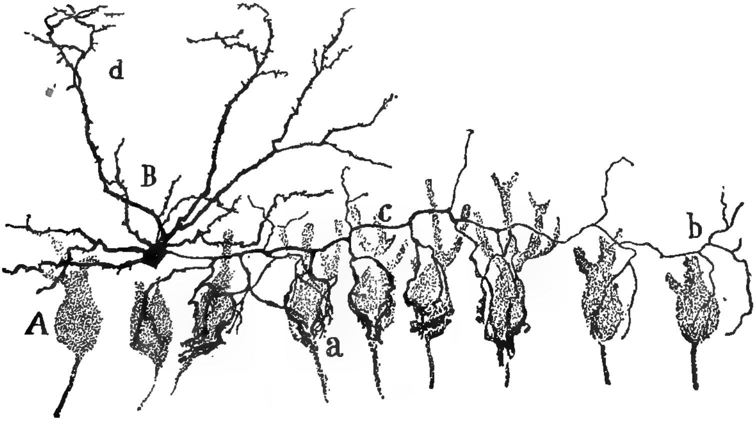

Fig. 634.—Basket-cell of cerebellum showing the arborisations of its axon over the cells of Purkinje. (Cajal.)

A, row of Purkinje cells ; B, basket-cell of molecular layer ; *d*, its dendrons ; *c*, its axon ; *a* and *b*, endings of axon.

Fibres of the cerebellar peduncles.—The peduncles of the cerebellum have been already studied in connexion with the medulla oblongata, pons, and mid-brain, but it may be convenient briefly to summarise what has there been stated. The *inferior peduncle* (restiform body) is composed mainly (1) of ascending fibres derived from the dorsal spino-cerebellar tract running in its outer part; and (2) of fibres from both olivary nuclei—but chiefly from that of the opposite side. The peduncle is also said to receive fibres from the nuclei of the gracile and cuneate funiculi, from cells and nuclei of the reticular formation of the medulla oblongata, and from the sensory nuclei of the cranial nerves, especially of the vestibular nerve. Most of the fibres of the peduncle pass to the lower part of the vermis, crossing to the opposite side over the fourth ventricle, but before doing so they give off strong collaterals to the hemisphere of the same side. Besides its ascending fibres the peduncle also contains a small bundle of fibres descending to the medulla oblongata from the nucleus tecti of the opposite side: this bundle bends round the superior peduncle to join the inferior peduncle, its fibres lying between those of the superior peduncle and Gowers' tract (Risien Russell). In the middle of the inferior peduncle is a very small nucleus of grey matter (Déjerine) which is almost completely concealed amongst the mass of white fibres (fig. 603, *n.r.*).

The *middle peduncle* is formed of fibres from the cells of the nuclei pontis which are passing to the opposite hemisphere of the cerebellum.

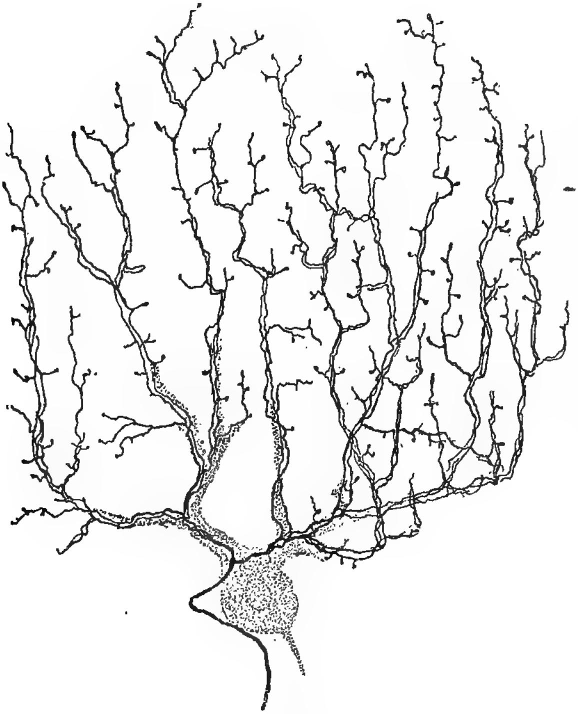
FIG. 635.—ENDING OF A "TENDRIL" FIBRE OVER THE DENDRONS OF A PURKINJE CELL: HUMAN. (Cajal.)

The *superior peduncle* is formed of fibres which mostly take origin in the corpus dentatum cerebelli, but some are said to arise in the hemisphere and pass through this nucleus. The superior peduncles decussate in the mid-brain across the raphe, and their fibres then bifurcate into ascending and descending branches. The ascending branches pass forwards and end in the red nucleus, but some fibres go past this into the ventral part of the thalamus. The descending branches are traceable into the dorsal part of the reticular formation of the pons.

The superior peduncle, as it issues from the hemisphere, is joined by the bundle of Gowers, which runs over it, and passes backwards along its mesial border to the vermis.

THE CEREBRUM.

The grey matter of the **cerebral cortex** is always described as if composed of a number of layers, but the strata are not sharply differentiated and they vary in number and in relative development in different regions of the cortex. Most of the cells are of a long, irregularly conical shape: these are known as the *pyramidal cells* of the cortex, a name which is somewhat inappropriate as a term intended to describe their form (fig. 637). They vary considerably in size in different levels. The following eight strata are generally distinguishable, but in some parts of the cortex a larger number can be made out, whilst in other parts there are fewer.

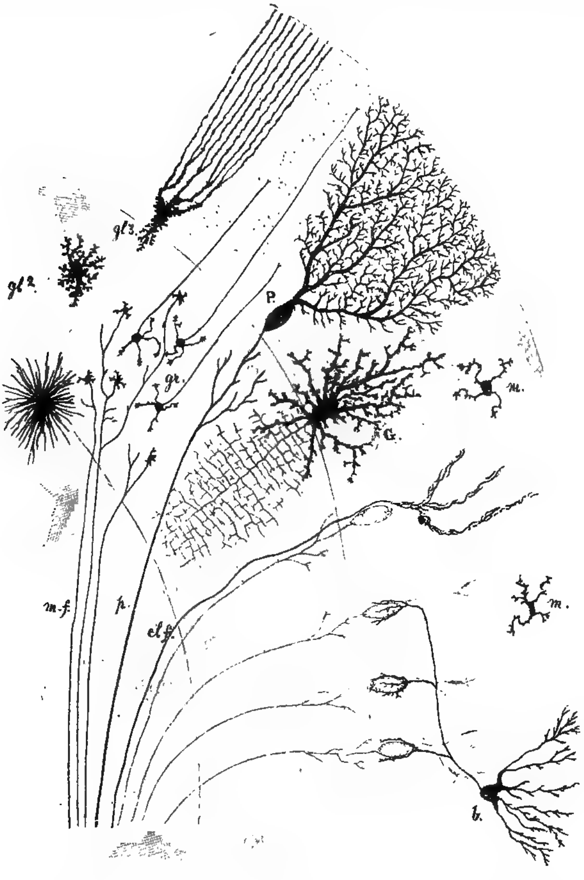

FIG. 636.—DIAGRAMMATIC SECTION OF CEREBELLUM TO SHOW THE CHARACTERS AND RELATIONS OF THE CELLS AND FIBRES MET WITH IN THE SEVERAL LAYERS AS EXHIBITED BY THE CHROMATE OF SILVER METHOD. (After Kölliker.)

P, a cell of Purkinje; G, a cell of Golgi; *b*, a basket-cell; *m*, *m*, other cells of the molecular layer; *gr*, granules; *p*, a nerve-fibre of the white substance derived from a Purkinje cell; *m.f.*, "moss"-fibres; *cl.f.*, a climbing fibre; gl^1, gl^2, gl^3, types of neuroglia-cells.

1. A peripheral stratum (*molecular* or *plexiform layer*) containing scattered nerve-cells and many neuroglia-cells (figs. 637, 638, 1). In the most superficial

part of this layer, immediately under the pia mater, is a thin stratum of nerve-fibres running parallel with the surface; the layer also contains a large number of ramified fibres. Most of the fibres of this plexiform layer are derived from nerve-cells of the deeper parts of the cortex. Intermingled with the fibres a few ramified cells, each with numerous dendrons and a long axon, are disposed parallel with the surface; the axons terminate by arborisations within the layer itself (*horizontal cells* of Cajal) (fig. 638). Other cells with shorter axis-cylinder processes also occur in this layer.

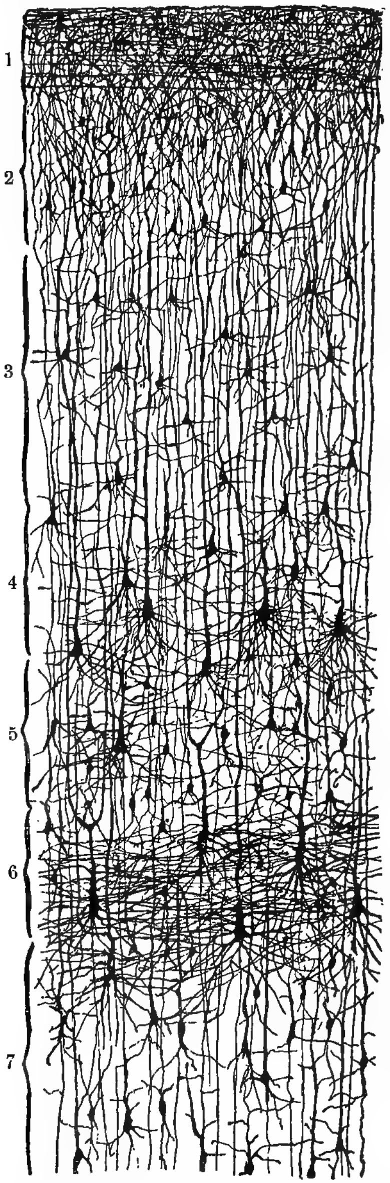

Fig. 637. — Ascending parietal (post-central) convolution, Golgi method. (Cajal.)

1, plexiform layer; 2, small pyramids; 3, medium pyramids; 4, superficial large pyramids; 5, granules; 6, deep large pyramids; 7, deep medium pyramids.

2. A layer of closely set small pyramidal nerve-cells, several deep (*layer of small pyramids*, fig. 637, 2). This layer also contains other cells with short axons.

3. A layer of medium-sized pyramidal cells less closely set, with small granule-like cells amongst them (*layer of medium-sized pyramids*, fig. 637, 3).

4. A layer of larger pyramidal cells (*superficial large pyramids*, fig. 637, 4).

5. A layer of small irregular cells (*small stellate cells*, fig. 637, 5). The large pyramids may extend down into this layer.

6. A layer of still larger pyramids (*deep large pyramids*, fig. 637, 6). In the motor region of the cortex, which in man appears to be confined to the pre-central gyrus and paracentral lobule, pyramidal cells of very large size (giant cells) occur within this layer, disposed in small clusters or "nests" (Betz, Bevan Lewis). The fibres of the pyramid tract arise from these giant cells. In some parts of the cortex the layer of large pyramids is either absent or is blended with the next layer.

7. A layer of medium-sized pyramidal cells (*deep medium pyramids*, fig. 637, 7).

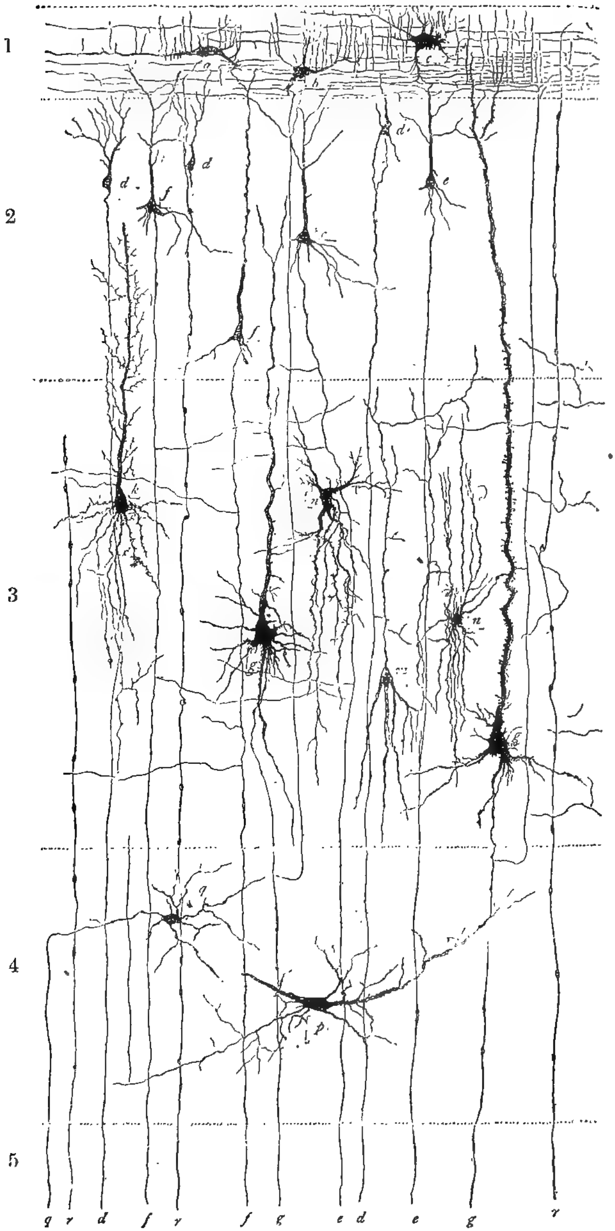

FIG. 638.—DIAGRAM SHOWING THE RELATIONS OF SOME OF THE CELLS OF THE CEREBRAL CORTEX. (Barker, after Starr, Strong, and Leaming.)

1, plexiform layer with horizontal cells of Cajal; 2, small (*d*, *e*) and middle size (*f*) pyramids; 3, large pyramids (*g*, *g*, *k*); also *m*, cell with axon passing towards the surface, but soon ramifying; *n*, *n*, cell of Golgi's second type, with axon ramifying in the adjacent grey matter; one of these belongs to the kind termed by Cajal "double-brush" cells; 4, polymorphous cells, of which *p* sends its axon towards the surface and *q* its axon into the medullary centre; 5, white or medullary centre, receiving axons from cells in the grey matter, and including also afferent fibres (*r*, *r*), ending in the grey matter.

8. A layer of small scattered cells (fig. 638, 4), many of a fusiform shape (*polymorphous layer*). This layer lies next to the white centre. In the island of Reil it is considerably developed, and is separated from the rest of the grey matter by a layer of white substance. It is here known as the *claustrum*, and on that account the layer is termed the *claustral layer*.

Some authorities describe the cortex as consisting only of three layers, viz.: the molecular layer, the layer of pyramids, and the layer of polymorphous cells; others of four, five, etc., up to nine. As a matter of fact, the complexity and the number of distinct layers largely vary in different regions.

Each pyramidal cell has several basal and one large apical dendron. This process extends to the plexiform layer, on approaching which it breaks up into numerous ramifications which have a general vertical direction and extend almost to the outer surface. The apical dendron is beset, both in its undivided part and in its branches, by minute spinous projections: similar "spines" may also be seen upon the basal dendrons. These projections are believed by some authors to be retractile (amœboid) and to be the means of effecting (or breaking) nervous connexion with afferent fibres; since they are in some preparations prominent, in others hardly visible: sometimes the dendrons are entirely free from them, and have an even outline or may be slightly moniliform. Each pyramidal cell has a single axon, which is usually directed towards the medullary centre, of which it forms one of the fibres: but the axon sometimes curves back and passes outwards again, ending in arborisations in one of the other layers. Intermingled with the pyramids and polymorphous cells are two other kinds of cells, viz.: (1) cells with axis-cylinder process ramifying near the cell-body: these occur in all the layers (fig. 638); and (2) small cells sending their axons towards the plexiform layer (Martinotti): these are found chiefly in the deeper layers of the grey matter.

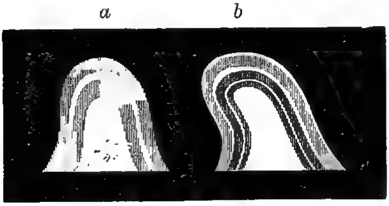

FIG. 639.—SECTIONS OF CEREBRAL CONVOLUTIONS. (After Baillarger.) Natural size.

a, from the neighbourhood of the calcarine fissure with only one white line clearly visible (the line of Gennari); *b*, ordinary type, with the superficial white layer and outer and inner lines of Baillarger shown.

From the white centre bundles of medullated nerve-fibres pass in vertical streaks through the deeper layers of the grey matter to lose themselves amongst the pyramidal cells of the more superficial layers (figs. 645, 648). Many large fibres, however, are seen running not vertically but obliquely into the grey centre from the white matter. Most of the vertically disposed fibres are the nerve-fibre processes of the pyramidal and polymorphous cells, and have taken origin in the cortex; others, including the oblique fibres just mentioned, are passing into the cortex, probably from the thalamus, to end in close arborisations amongst the cells (fig. 640).

Besides these vertical strands of fibres there are others which lie in planes parallel to the surface of the cortex, and which are derived partly from the fibres which enter the cortex from the white matter, partly from the collaterals which are given off from the axis-cylinder processes of the cortical cells themselves. The planes in which these fibres occur are: (1) near the surface, in the plexiform (molecular) layer: this superficial stratum of white fibres is best marked in the hippocampal region; (2) in the layer of medium-sized pyramids: here the fibres give the appearance of a whitish line in the section of the grey matter (*outer line of Baillarger*, fig. 639, *b*). There is a particularly dense plexus of fibres in this situation in the visual region of the cortex (all over the occipital lobe in animals but in man only in the convolutions bounding the calcarine fissure), producing a very distinct line, known as the *line of Gennari* (fig. 639, *a*). This plexus of nerve-fibres is in intimate association with certain (large and small) stellate cells which are characteristic of the visual region. (3) In most regions of the brain, in the plane of the layer of large pyramids, another white line is seen; this is known as the *inner line of Baillarger* (fig. 639, *b*). The planes in which these white lines are found are characterised, especially in the occipital and temporal lobes, by the presence amongst the pyramids of great numbers of very small nerve-cells, amongst which the white fibres of the layers ramify and probably terminate. According to Cajal, in the brain of man as compared with the lower mammals, there is a marked preponderance in the grey matter of the cortex cerebri of the cells with short axis-cylinder ramifying near the cell body. Such cells are most numerous amongst the stellate cells and the small pyramids.

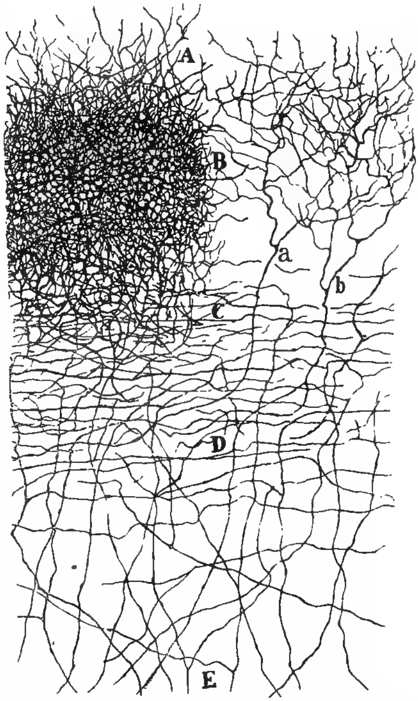

FIG. 640.—PREPARATION SHOWING SOME OF THE AFFERENT FIBRES OF THE ASCENDING FRONTAL GYRUS: HUMAN. (Cajal.)

A, part of second layer; B, layer of medium-sized pyramids with close terminal plexus; C to D, intermediate plexus of horizontal fibres; E, deep plexus of large oblique afferent fibres; *a*, *b*, afferent fibres arborising in the layer of middle pyramids, amongst which they form, along with fibres derived from cells in the cortex itself, the dense plexus which is shown in the left half of the figure. The efferent fibres are not shown in this figure.

The axis-cylinder processes of the pyramidal cells pass into the white centre (fig. 641). Here some of them are continued into the corpus callosum and through this to the cortex of the opposite hemisphere as *commissural fibres*; others form *association-fibres* which eventually pass again into the grey matter of other parts of the same hemisphere; whilst others again, especially those of the largest pyramidal cells, extend downwards as *projection fibres* through the corona radiata and internal capsule. These include the fibres of the pyramid tract and of the cortico-pontine tract. As the projection fibres pass through the grey and white matter of the hemisphere they give off collateral fibres to the adjacent grey matter, to the corpus callosum, and to the corpus striatum and optic thalamus, and some probably end in these masses of grey matter.

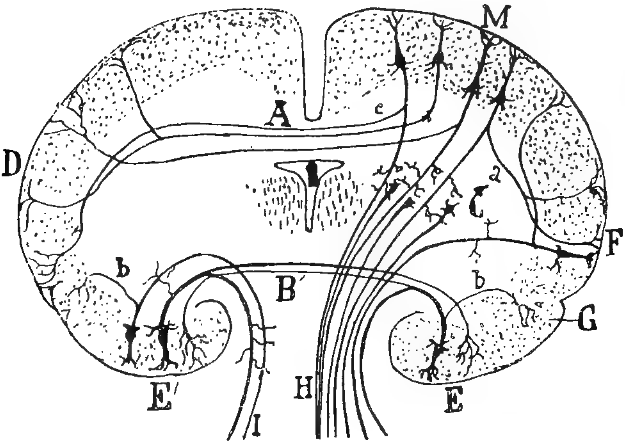

FIG. 641.—DIAGRAM TO ILLUSTRATE THE ORIGIN AND COURSE OF THE ASSOCIATION, COMMISSURAL AND PROJECTION FIBRES OF THE CEREBRAL CORTEX. (Cajal.)

A, commissural fibres connecting cells of the motor cortex, M, with the opposite hemisphere; B, commissural fibres connecting the opposite sensory regions of the cortex; C, cells in basal ganglia giving origin to descending fibres and receiving collaterals from projective fibres; H, of the cells of the motor cortex; D, E, endings of commissural fibres in grey matter; F, G, endings of association fibres in grey matter; I, a projective fibre from sensory (hippocampal) cortex; *a*, *b*, *c*, collaterals.

The *neuroglia of the cortex cerebri* like that of the cerebellum contains three types of glia-cell, viz.: spider cells, arborescent cells, and cells the

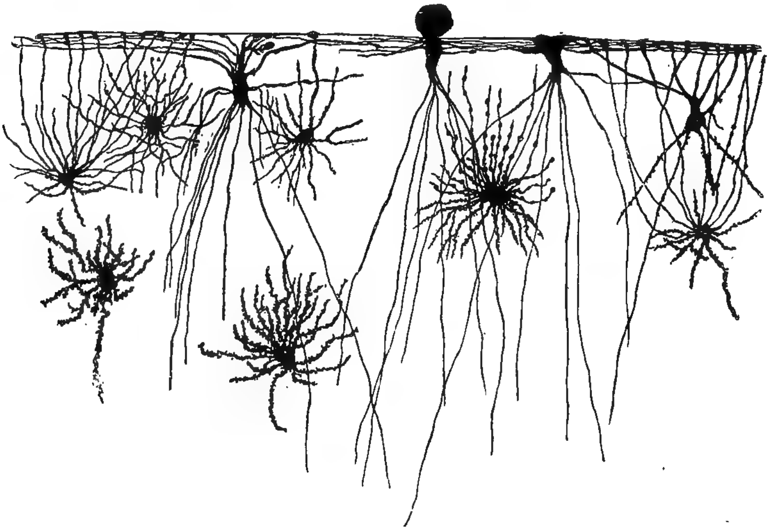

FIG. 642.—NEUROGLIA-CELLS OF CORTEX CEREBRI: GOLGI METHOD. (G. Retzius.)

body of which is placed near the surface while the processes extend for a considerable distance vertically into the grey matter (fig. 642). The ependyma cells of the ventricles are prolonged, like the cells of the central canal of the cord, in the form of long neuroglia-like fibres far into the adjacent grey matter.

Special features of certain parts of the cortex.—There is, as already stated, a great amount of variation met with in the relative extent of development of the above layers. This is exemplified in the accompanying drawings by Cajal (figs. 643 to 648) of convolutions of the human brain. From these it will be seen that smaller-sized cells prevail in certain regions of the cortex (occipital, temporal); larger and fewer cells in others (frontal, parietal, limbic). Nests or groups of "giant" cells are characteristic of the "motor" region (precentral gyrus and paracentral lobule in man and anthropoid apes); these cells give origin to the fibres of the pyramid tract, and undergo Nissl degeneration when those fibres are severed (Page May). The occipital region (in man, the neighbourhood of the calcarine fissure) is especially characterised by containing a great number of the small stellate cells and by the presence in the layer superficial to these of a stratum of very large stellate cells with long spreading dendrons (fig. 646, 4): amongst these small and large stellate cells the optic fibres from the lateral geniculate bodies ramify. A preponderance of small stellate cells is also seen, but to a less extent, in sections of the temporal lobe. In the prefrontal and parietal regions they are less numerous, and least in the motor cortex. The first temporal gyrus is characterised by the presence in nearly all the layers, but especially the deepest, of special large cells with widely spreading dendrons and an axon passing towards the white substance but giving off many collaterals in the grey matter. There are also in this gyrus very many cells with their axons ramifying in a most complex manner near the cell-body, mainly in a plane vertical to the surface. The hippocampal gyrus has groups or islets of stellate cells (groups of small cells alternating with groups of larger) in the plexiform layer. The cortex of the insula has special cells similar to those in the first temporal gyrus, and is further characterised by the peculiar spindle-shape of many of the large pyramids.

The size and number of the medullated fibres of the grey matter vary in different regions.[1] In some they are large and numerous (motor part of frontal lobe, calcarine area, hippocampal area), in others fine and much less conspicuous (gyrus fornicatus, temporal area, parietal area, prefrontal area, insula and lobus pyriformis), whilst an intermediate condition presents itself in the occipital area (except the calcarine region), the transverse temporal gyri and superior temporal gyrus, and the part of the frontal immediately in front of the motor region. These differences have been employed by Campbell

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[1] Except, perhaps, in the bundle of Lissauer in the cord there are no non-medullated fibres in the central nervous system, exclusive of a few which pass to the membranes and blood-vessels from the sympathetic chain of ganglia.

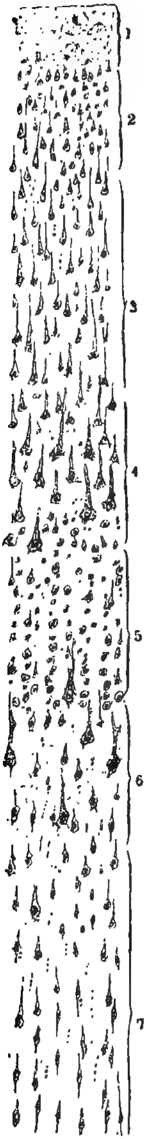

Fig. 643.

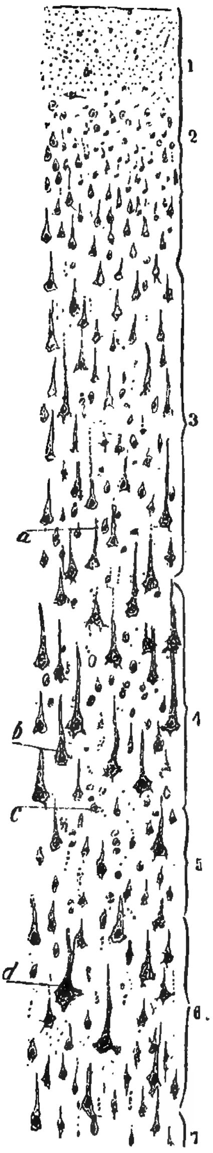

Fig. 644.

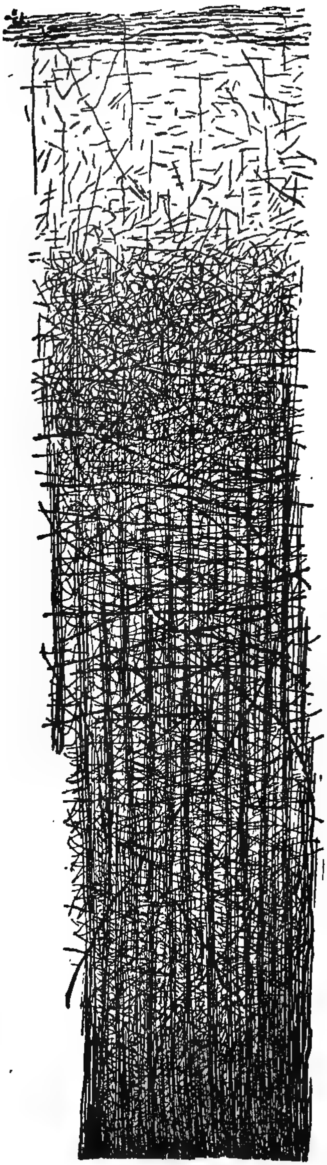

Fig. 645.

Fig. 643.—Section of post-central gyrus of man, stained by Nissl's method. (Cajal.)

1, plexiform layer; 2, small pyramids; 3, medium pyramids; 4, superficial large pyramids; 5, small stellate cells (granules); 6, deep large and medium pyramids; 7, fusiform cells.

Fig. 644.—Section of precentral gyrus (motor cortex), stained by Nissl's method. (Cajal.)

1 to 6 as before; *a*, *c*, small cells amongst the pyramids; *b*, a large pyramid; *d*, a giant cell of Betz.

Fig. 645.—Section of one of the motor convolutions (man), stained by Weigert-Pal method. (Cajal.)

Only the nerve-fibres are seen in this preparation.

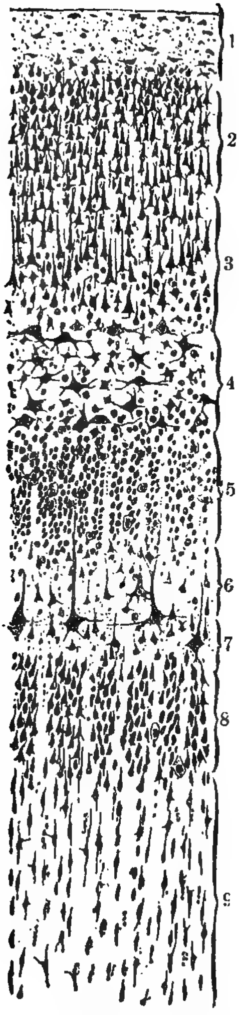

FIG. 646.

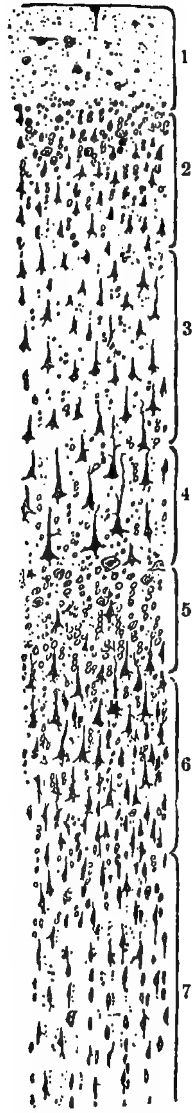

FIG. 647.

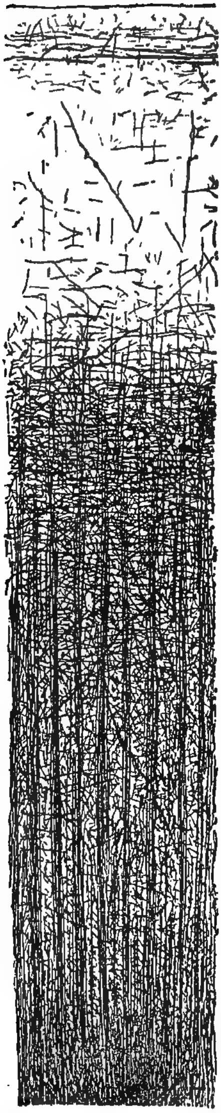

FIG. 648.

FIG. 646.—CALCARINE (VISUAL) CORTEX OF MAN. (Cajal.) Nissl's method.

1, plexiform layer; 2, small pyramids; 3, medium pyramids; 4, large stellate cells (characteristic of this part of the cortex); 5, small stellate cells; 6, a deep plexiform layer, containing some small pyramids; 7, large pyramids; 8, layer of small and medium pyramids with bent ascending axons; 9, fusiform cells.

FIG. 647.—SECTION OF FIRST TEMPORAL GYRUS (ACOUSTIC CORTEX) OF MAN, STAINED BY NISSL'S METHOD. (Cajal.)

1, plexiform layer; 2, layer of small pyramids; 3, superficial medium pyramids; 4, large pyramids; 5, small stellate cells (granules); 6, deep medium pyramids; 7, fusiform cells.

FIG. 648.—SECTION OF THE FIRST TEMPORAL GYRUS (MAN), STAINED BY WEIGERT-PAL METHOD. (Cajal.)

Only the nerve-fibres are seen in this preparation.

in an attempt to differentiate the functions of the various cerebral regions by a comparison of their structure.[1]

THE RHINENCEPHALON.

The **rhinencephalon** (olfactory region of the telencephalon), on account of the peculiarities of its structure, its importance in most animals, and the fact that it has been the part of the telencephalon to appear first in phylogenetic development, merits a special description, although in man and Primates generally, and in some other (microsmatic) mammals, it is reduced to a comparatively rudimentary condition. In the so-called osmatic (macrosmatic) mammals the rhinencephalon consists of a large hollow *olfactory bulb*, the cavity of which communicates with the lateral ventricle. It forms the anterior termination of a thick *olfactory lobe* which broadens out behind and becomes continuous with the *hippocampal gyrus* and *hippocampus*. The whole forms a pyriform mass, which is separated from the

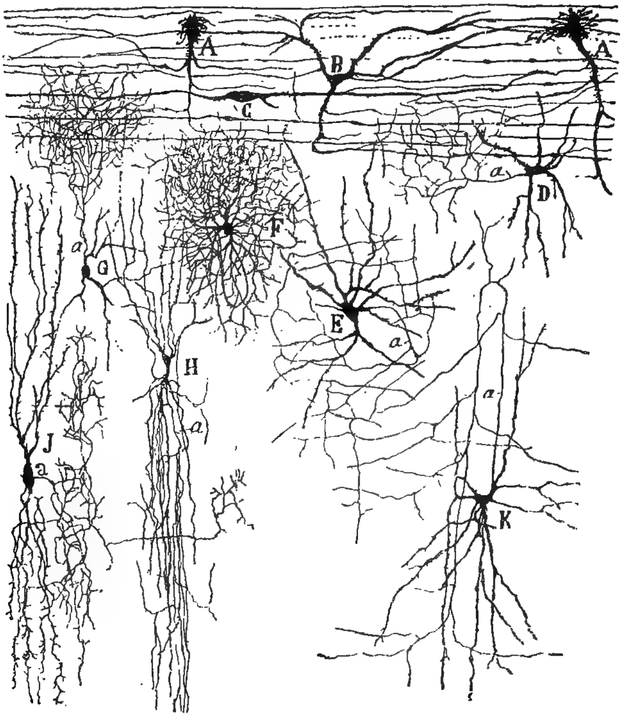

FIG. 649.—SUPERFICIAL LAYERS OF MOTOR CORTEX OF CHILD: GOLGI METHOD. (Cajal.)

A, B, C, cells of Cajal in plexiform layer; D to K, cells of type ii. of Golgi (with axons ramifying near cell-body); H, J, "double-brush" types of cell.

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[1] For further details regarding the cells and fibres of different regions of the cortex and the special characters of the several regions see the volume of *Quain's Anatomy* dealing with Neurology.

rest of the cortex by a well-marked fissure—the *limbic fissure*—and has special connexions through the anterior commissure and fornix with other parts of the brain on the same and on the opposite side.

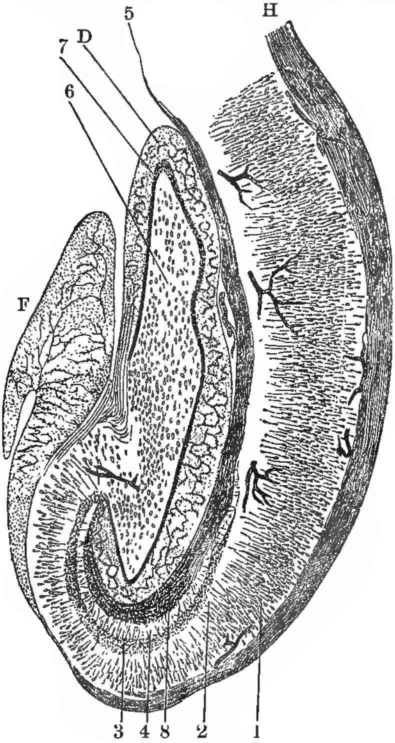

FIG. 650.

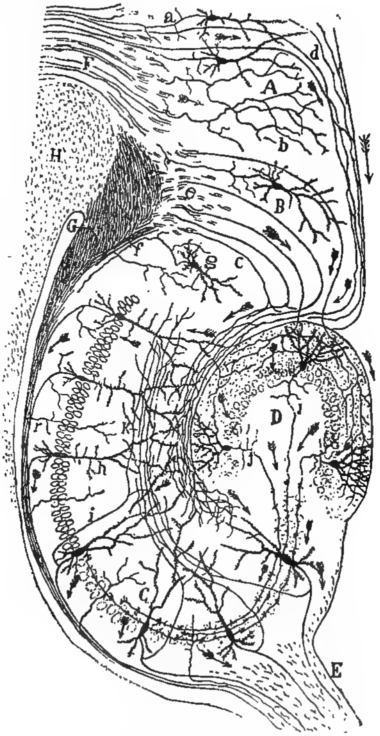

FIG. 651.

FIG. 650.—SECTION ACROSS THE HIPPOCAMPUS MAJOR, DENTATE FISSURE, DENTATE FASCIA AND FIMBRIA. (W. Krause.)

D, fascia dentata, or dentate convolution; E, fimbria, composed of longitudinal fibres here cut across; H, medullary centre of the hippocampal gyrus prolonged around the hippocampus, as the so-called alveus, into the fimbria; 1, layer of large pyramidal cells; 2, their processes (stratum radiatum); 3, stratum granulosum; 4, plexiform layer (stratum laciniosum); 5, superficial white layer; 6, nerve-cells of fascia dentata; 7, stratum granulosum of fascia dentata; 8, termination of superficial white layer, its fibres becoming longitudinal.

FIG. 651.—HIPPOCAMPAL REGION: GOLGI METHOD. (Cajal.)

A, B, hippocampal gyrus; C, hippocampus major; D, dentate gyrus; E, fimbria; F, white matter of hippocampal gyrus; G, in lateral ventricle; the line points to the crossed spheno-hippocampal bundle; H, fibres of corpus callosum.

a, efferent fibres of hippocampal gyrus; b, afferent fibres of hippocampal gyrus; c, afferent fibres of hippocampus and dentate gyrus; d, others perforating grey matter of hippocampal gyrus; e, others cut obliquely; f, fibres of alveus; g, h, cells of hippocampus major sending their axons into the alveus and towards the fimbria; i, k, collaterals from these axons passing to the molecular layer; r, collateral fibres of alveus. The arrows indicate the probable course of the nerve impulses.

In man the rhinencephalon consists anteriorly of the small *olfactory bulb* from which the thin *olfactory tract* extends backwards to the grey matter at the base of the brain and to the hippocampal region. Posteriorly the cortex of the rhinencephalon is doubled in so as to form a projection (*hippocampus major*) in the descending cornu of the lateral ventricle: its edge here thins off and is continued merely as a thin layer of epithelium covering the choroid plexus of the pia mater, which is invaginated into the ventricle. At this thin edge the white matter comes to the surface as the *fimbria* which is continued on each side into the commissural band known as the *fornix*. Lying along the fimbria is the small and half-concealed *dentate gyrus*, which is formed by the sharp bending of the grey matter, and is traceable round into the hippocampus major, the hippocampal fissure being between them: the hippocampus major is continuous externally with the *gyrus hippocampi*. The olfactory tract is connected directly with the hippocampal region by a lateral root, whilst a mesial root passes into the anterior commissure and forms a connexion with the rhinencephalon of the opposite side. The structure and connexions of all these parts as they occur in man may be briefly given.

In the region of the hippocampus major (figs. 650, 651) the cortex is simpler in structure than elsewhere, and in the hippocampus major itself, which is an infolded part of the cortex, the pyramids are reduced to a single layer of large cells lying in the deeper portion and sending their apical dendrons as long fibres into the plexiform layer. The plexiform layer and the superficial white stratum which overlies it are both very strongly marked, the plexiform layer having a distinctly reticular aspect, due partly to neuroglia-cells, partly to the arborescence of the dendrons of the pyramids. The plexiform layer is here termed *stratum laciniosum*; internal to it near the dentate gyrus is a layer of closely packed small cells termed *stratum granulosum*. The pyramidal cells lie close to a white layer known as the *alveus*. This is the part of the hippocampus seen within the ventricle, and represents the white matter of the hemisphere, here greatly attenuated. The alveus is prolonged externally into the fimbria, in which its fibres become longitudinal in direction and are continued into part of the fornix.

In the dentate gyrus (*fascia dentata*, figs. 650, 651) the pyramidal cells (6) are arranged in an irregularly radiating manner. They occupy the centre of the convolution, and are surrounded by a ring of closely packed small cells (*stratum granulosum* of fascia dentata, fig. 650, 7). External to these small cells is a thick plexiform layer (*stratum laciniosum*).

The anterior part of the hippocampal gyrus, which is known as the lobus pyriformis, and receives the lateral root of the olfactory tract, is characterised by the presence in the plexiform layer of peculiar nests of nerve-cells. The cells in these nests are of two types, viz., large polymorphous cells and small pyramidal cells, each being confined to its own nest. This part of the cortex is regarded by Cajal as the true olfactory region. In some animals the anterior perforated space forms a distinct prominence of the cortex (tuberculum - olfactorium) and this is also characterised by cell-nests (*islets of Calleja*). They also occur in the cortex of the hippocampal fissure.

The *olfactory tract* is an outgrowth of the brain which was originally hollow, and remains so in many animals; but in man the cavity has become obliterated, and the centre is occupied by neuroglia, containing no nerve-cells.

Outside the central neuroglia lies the white or medullary substance, consisting of bundles of longitudinal white fibres. Most externally is a thin superficial layer of neuroglia.

The *olfactory bulb* (fig. 652) has a more complicated structure than the tract. Dorsally there is a flattened ring of longitudinal white bundles enclosing neuroglia (1, 2, 3), as in the olfactory tract, but below this ring several layers are recognised as follows :—

1. A *white or medullary layer* (fig. 652, 4, 5), characterised by the presence of a large number of small cells ("granules") with reticulating bundles of medullated nerve-fibres running longitudinally between them.

2. A *layer of large nerve-cells* (6), with smaller ones ("granules") intermingled, the whole embedded in an interlacement of fibrils which are mostly derived from the cell-dendrons. From the shape of most of the large cells of this layer (fig. 653, *m.c.*) it has been termed the "mitral" layer. These cells send their axons upwards into the next layer, and they eventually become fibres of the olfactory tract and pass along this to the base of the brain, giving off numerous collaterals into the bulb as they run backwards.

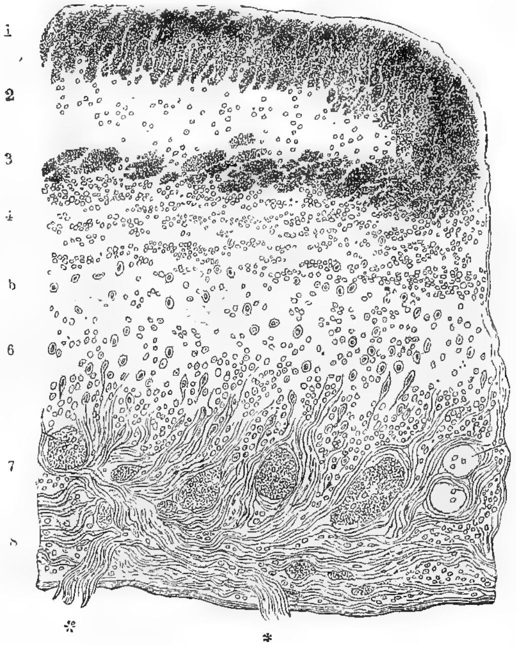

FIG. 652.—SECTION ACROSS A PART OF THE OLFACTORY BULB. (Henle.)

1, 3, bundles of very fine transversely cut nerve-fibres, forming the flattened medullary ring, enclosing the central neuroglia, 2: this ring is the anterior continuation of the olfactory tract; 4, 5, white layer with numerous small cells (granules); 6, mitral-cell layer; 7, layer of olfactory glomeruli; 8, layer of olfactory nerve-fibres, bundles of which are seen at ✻ passing through the cribriform plate of the ethmoid bone.

3. The *layer of olfactory glomeruli* (fig. 652, 7; fig. 653, *gl.*). This consists of rounded nest-like interlacements of fibrils which are derived on the one hand from the terminal arborisations of the non-medullated olfactory fibres which form the subjacent layer, and on the other hand from arborisations of dendrons of the large "mitral" cells of the layer above. There are also a few small nerve-cells immediately external to and extending within the glomeruli (periglomerular cells). These are short axoned cells and appear to connect neighbouring glomeruli.

4. The *layer of olfactory nerve-fibres* (fig. 652, 8; fig. 653, *olf.n.*). These are all non-medullated, and are continued from the olfactory fibres of the olfactory mucous membrane of the nasal fossæ. In this mucous membrane they take origin from the bipolar olfactory cells, which are characteristic of the membrane (see Lesson XLIX., fig. 696), and they end in arborisations within the olfactory glomeruli, where they come in contact with the arborisations of the mitral cells. The relations of the olfactory cells and fibres to the mitral cells, and the continuation of the axis-cylinders of the latter upwards and backwards in the olfactory tract, are shown in the accompanying diagrams (figs. 653, 654). Besides the centripetal nerve-fibres there are a certain number of centrifugal fibres which end by ramifying in the olfactory bulb amongst the mitral cells.

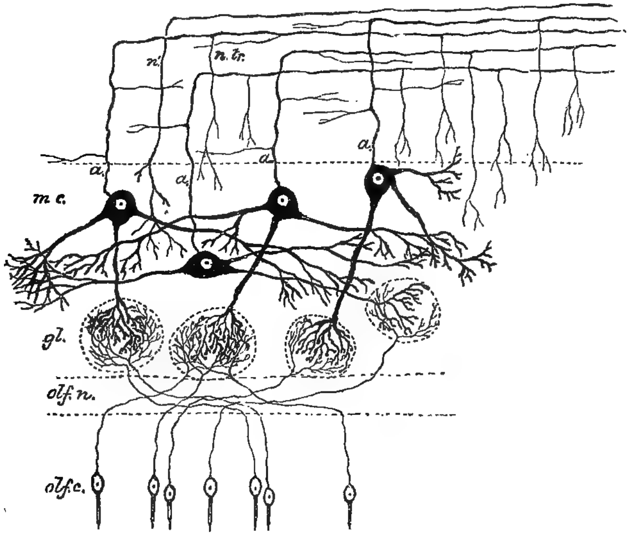

FIG. 653.—DIAGRAM TO SHOW THE RELATIONS OF CELLS AND FIBRES IN THE OLFACTORY BULB.

olf.c, olfactory cells in the olfactory mucous membrane, sending their basal processes as (non-medullated) nerve-fibres into the deepest layer of the olfactory bulb (*olf.n.*); *gl.*, olfactory glomeruli containing the terminal arborisations of the olfactory fibres and of processes from the mitral cells; *mc.*, mitral cells, sending processes down to the olfactory glomeruli, others laterally to end in free ramifications in the nerve-cell layer, and their axis-cylinder processes, *a*, *a*, upwards, to turn sharply backwards and become fibres of the olfactory tract (*n.tr.*). Numerous collaterals are seen coming off from these fibres; *n'*, a nerve-fibre of the olfactory tract ending in a free ramification in the olfactory bulb.

As shown in fig. 654, many of the fibres of the olfactory tract pass to the hippocampal region of the brain, terminating by arborescence in the grey matter (molecular layer) of the base of the olfactory lobe in the region of the anterior perforated space, as well as in that of the uncus and the hippocampal gyrus. Fibres are also given off from the olfactory tract to the *anterior commissure* which proceed to the opposite tract and bulb. Besides these the anterior commissure contains many fibres which are passing from the hippocampal region on one side to the corresponding region on the opposite side of the brain. From the pyramid-cells of the base of the olfactory lobe and hippocampal gyrus fibres pass to the grey matter of the hippocampus, and from the pyramid-cells of the hippocampus others proceed by way of the fimbria and fornix to the hippocampus of the other side, to the subcallosal gyrus and septum pellucidum, to the ganglion of the habenula, and finally by the anterior pillar of the fornix to the corpora mammillaria.

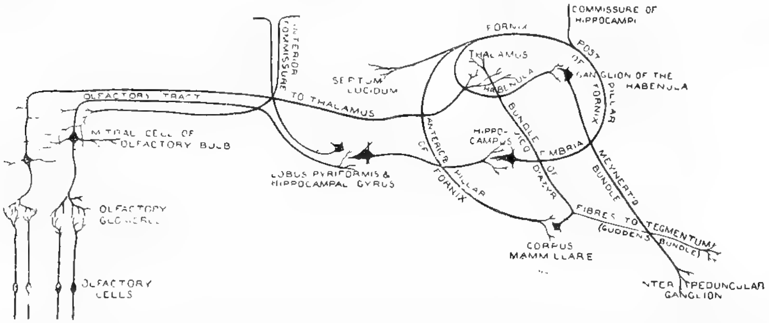

FIG. 654.—DIAGRAM OF THE OLFACTORY PATH IN THE BRAIN. To simplify the diagram the various divarications of the olfactory path have been represented by branchings of individual fibres, although in some cases the divergence is brought about by the turning aside of bundles of entire fibres.

CORPUS STRIATUM.

Besides the grey matter of the cerebral cortex the cerebral hemispheres conceal in their deeper parts certain other masses of grey substance (figs. 655, 656). The principal of these are the *corpus striatum* (*nucleus caudatus*, *n.c.*, and *nucleus lenticularis*, *n.l.*) and *thalamus* (*th.*). Between them run the bundles of white fibres which are passing downwards to the crus cerebri, forming a white lamina termed the *internal capsule*. Above the level of these nuclei the internal capsule expands into the medullary centre of the hemisphere. Below the thalami are the prominent ganglia known as *corpora albicantia* or *mammillaria*. Of these the optic thalami and corpora mammillaria have already been noticed.

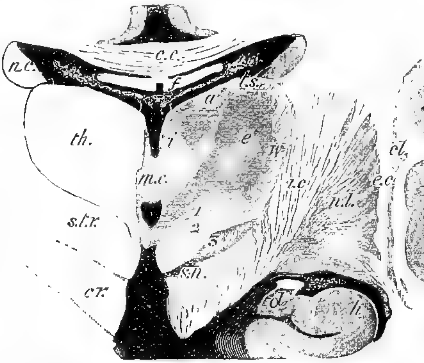

FIG. 655.—TRANSVERSE SECTION THROUGH THE CEREBRUM IN THE REGION OF THE MIDDLE COMMISSURE. Natural size.

c.c., corpus callosum; *f*, fornix; *n.c.*, nucleus caudatus; *th*, thalamus; *s.t.r.*, subthalamic region; *cr.*, crusta passing into internal capsule; *s.n.*, substantia nigra; *a*, *e*, *i*, various nuclei of thalamus; *e*, its latticed layer; *1*, *2*, *3*, parts of subthalamus; *n.l.*, nucleus lenticularis; *e.c.*, external capsule; *cl.*, claustrum; *I*, insula; *m.c.*, middle commissure; above and below it is the third ventricle, communicating above on each side through the foramen of Monro with the lateral ventricle. Below the fornix are seen the choroid plexuses; *t.s.*, stria terminalis.

The *nucleus caudatus* of the corpus striatum is composed of a reddish-grey substance containing nerve-cells some with long, others with short axon-processes; some of the cells with long processes being very large. It receives fibres from the part of the internal capsule which separates it from the nucleus lenticularis. Next to the lateral ventricle it is covered by a thin layer of neuroglia, and over this by the epithelium of the cavity (ependyma).

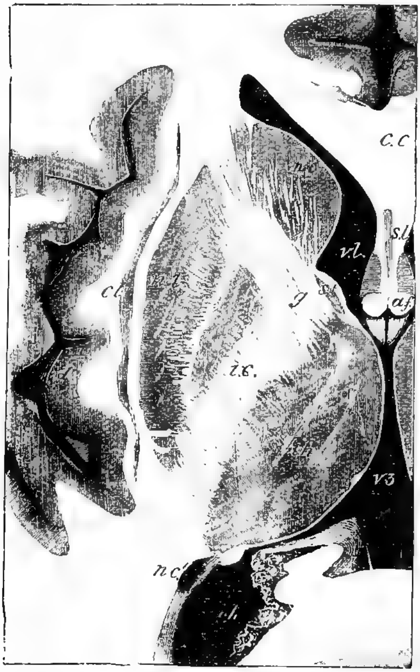

Fig. 656.—Horizontal section through the thalamus and corpus striatum. Natural size.

v.l., lateral ventricle, its anterior cornu; *c.c.*, corpus callosum; *s.l.*, septum pellucidum; *a.f.*, anterior pillars of the fornix; *v.3*, third ventricle; *th*, thalamus; *st.*, stria medullaris; *n.c.*, nucleus caudatus, and *n.l.*, nucleus lenticularis of the corpus striatum; *i.c.*, internal capsule; *g*, its angle or genu; *n.c'.*, tail of the nucleus caudatus appearing in the descending cornu of the lateral ventricle; *cl.*, claustrum; *I*, insula.

The *nucleus lenticularis*, which corresponds in position internally with the island of Reil externally, is divided by two white laminæ into three zones. It is separated from the nucleus caudatus and optic thalamus by the *internal capsule* (*i.c.*), which consists of the bundles of medullary fibres which are passing between the white centre of the hemisphere and the crus cerebri. It receives on its inner side many white fibres from the capsule; these impart to it a radially striated aspect. Many of the nerve-cells of the nucleus lenticularis contain yellow pigment. The fibres of the *ansa lenticularis* (p. 472) appear to arise from some of them, but the exact course and destination of these fibres is not known.

The *internal capsule* (*i.c.*) is continued below into the *crusta*. It consists mainly of projection-fibres, which are connected with the cortex cerebri, and are passing to or from the corpus striatum, thalamus, mid-brain, pons, medulla oblongata, and spinal cord. A horizontal section across the internal capsule (fig. 656) shows it to be bounded laterally by the lenticular nucleus, mesially by the caudate nucleus, the stria medullaris, and the thalamus. Such a section shows a sharp bend in the plane of the capsule—the genu. The fibres from the motor region of the cortex (pyramid tract) pass down in the part of the capsule extending from the genu as far as the posterior limit of the lenticular nucleus. In this area the fibres for the head and eyes are massed chiefly in the anterior part: those for the lower limb in the posterior part, while those for the face, arm, and trunk occupy intermediate positions from before backward, in the order named (Beevor and Horsley), but without being strictly confined to definite zones.

The fibres from the cortex to the thalamus lie mainly in the anterior limb of the internal capsule, while the afferent fibres from the thalamus to the cortex occur in the posterior part of the posterior limb; but they extend forwards so as to mingle with the descending fibres of the pyramid tract.

MEMBRANES OF THE BRAIN.

The membranes of the brain (fig. 657) are similar in general structure and arrangement to those of the spinal cord with which they are continuous through the occipital foramen. The dura mater is, however, more closely adherent to the inner surface of the bony enclosure than is the case in the vertebral canal, while the arachnoid is in most places close to the dura mater, and separated from the pia mater by a wide subarachnoid space, which is bridged across by finely reticulating bands of areolar tissue. In the vicinity of the longitudinal sinus, small rounded elevations (*arachnoidal villi*, *Pacchionian glands*) project into the dura mater, and even become embedded in the skull itself. The pia mater is closely adherent to the surface of the brain, and dips into all the sulci, but without forming actual folds (Tuke). In it the blood-vessels ramify before passing into the substance of the brain, and they are accompanied, as they thus enter the cerebral substance, by prolongations of the pia mater, which do not, however, closely invest them, but leave a clear space around each vessel, presumably for the passage of lymph (perivascular space). The capillary network is much closer in the grey than in the white matter. The larger veins are enclosed by two layers of the dura mater, within which they run in certain parts in the form of sinuses; the chief of these are found at the lines of junction of the principal folds (falx, tentorium) with the main portion of the membrane.

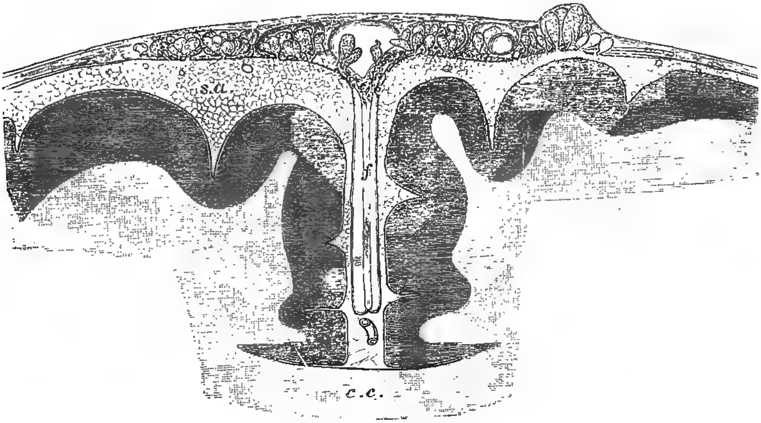

FIG. 657.—SECTION THROUGH THE UPPER PART OF THE BRAIN TO SHOW THE RELATIONS OF ITS MEMBRANES. (Axil Key and Gustaf Retzius.)

c.c., corpus callosum; *f*, great longitudinal fissure between the hemispheres containing the projection of dura mater known as the falix cerebri; *s.a.*, subarachnoid space between pia mater which closely covers the surface of the brain and dura mater which lines the skull. The arachnoid is in this part close to the dura mater into which and into the great longitudinal venous sinus in the middle it sends villous projections (Pacchionian glands).

LESSONS XLVI., XLVII., AND XLVIII.

THE EYE.

1. SECTIONS of the eyelid vertical to its surfaces and across its long axis.

Notice the long sacculated Meibomian glands lying in dense connective tissue close to the conjunctival surface, their ducts opening at the margin of the lid. External to these the small fibres of the orbicularis palpebrarum are cut across; a few of the fibres of the muscle lie on the conjunctival side of the duct. A short distance from the Meibomian gland may be observed a tolerably large sebaceous gland: outside this again are the eyelashes. In the skin covering the outer surface of the eyelid a few small hairs may be seen. At the attached part of the eyelid are some bundles of involuntary muscular fibres cut longitudinally in the section, and in the upper eyelid the fibrous insertion of the elevator muscle may be observed attached to the dense connective tissue.

Make a general sketch under a low power.

2. Sections through the posterior part of an eyeball (man or pig). These sections will show the relative thickness of the several coats and the layers of which each coat is formed. Sections which pass through the point of entrance of the optic nerve will also exhibit the manner in which the nerve-fibres pierce the several coats to reach the inner surface of the retina. The modifications which are found in the neighbourhood of the yellow spot may be made out in sections through that region; but they must be taken from the human eye.

3. Sections of the anterior half of an eyeball. These sections should pass through the middle of the cornea. The lens may be left *in situ*, but this renders the preparation of the sections and the mounting of them difficult on account of the extreme hardness which is imparted to the lens-tissue by alcohol.[1]

In these sections make a general sketch under a low power, showing the relations of the several parts one with another; and study carefully, and sketch in detail, the layers of the cornea, the junction of the cornea and sclerotic, the ciliary muscle, the muscular tissue of the iris, the mode of suspension of the lens, and the pars ciliaris retinæ.

4. Mount in glycerine thin tangential sections of a cornea stained with chloride of gold by Cohnheim's method; if from the frog, the cornea can be torn with fine forceps into thin lamellæ, which are mounted whole. Sketch three or four of the connective-tissue cells (corneal corpuscles). The arrangement and distribution of the nerve-fibres and their termination amongst the epithelium-cells as shown in chloride of gold preparations have been already studied (Lesson XIX.).

5. Mount in glycerine or dammar sections of a cornea which has been stained with nitrate of silver. Notice the branched cell-spaces corresponding with the connective-tissue cells of the last preparation.

This preparation is best made by rubbing the surface of the cornea of a recently killed animal with lunar caustic, first scraping off the epithelium with a scalpel. After ten minutes (by which time the nitrate of silver will have penetrated the thickness of the cornea) the eye is washed with distilled water, and exposed to the light. When brown, tangential sections may be made, for which purpose the stained cornea may be hardened in alcohol.

6. Remove the sclerotic from the anterior part of an eye which has been preserved in Müller's fluid, and tear off thin shreds from the surface of the choroid, including amongst them portions of the ciliary muscle. Stain the shreds with hæmatoxylin and mount them in glycerine. Sketch the branched pigment-cells, the elastic network, the mode of attachment of the fibres of the ciliary muscle, etc.

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[1] The celloidin method of embedding is best for preparations of this kind.

7. Injected preparation of choroid and iris. Mount portions of the choroid coat and iris from an eye (preferably of an albino rabbit or rat), the blood-vessels of which have been filled with coloured injection. Make sketches showing the arrangement of the capillaries and veins.

8. Teased preparation of human retina. Break up with needles in a drop of glycerine a minute fragment of retina which has been placed in 1 per cent. osmic acid solution for some hours, and has subsequently been kept in dilute glycerine. Complete the separation of the retinal elements by tapping the cover-glass. Draw carefully under a high power some of the isolated elements—*e.g.* the rods and cones with their attached fibres and nuclei, the inner granules, the ganglion-cells, the fibres of Müller, hexagonal pigment-cells, etc. In some of the fragments the arrangement of the elements in the retinal layers may be made out even better than in actual sections.[1]

Measure the length and diameter of some of the cones, the length of the cone-fibres, and the diameter of some of the outer and inner nuclei.

9. Teased preparation of frog's retina. To be prepared in the same way as 8. Notice the very large rods, their outer segments breaking up into disks, and the relatively small cones. Also the pigment extending between the rods, the distance varying according as the eye has been kept in the dark or in the light before treatment with osmic acid. A fresh frog-retina may also be teased in Ringer.

10. Sections of retina of ox or dog, which have been prepared by Golgi's method. A curled-up piece of fresh retina is placed in osmium-bichromate mixture and is subsequently treated with nitrate of silver solution.[2]

11. Teased preparation of lens. Separate in water the fibres of a crystalline lens which has been macerated for some days in bichromate of potassium. Sketch some of the fibres, together and separate.

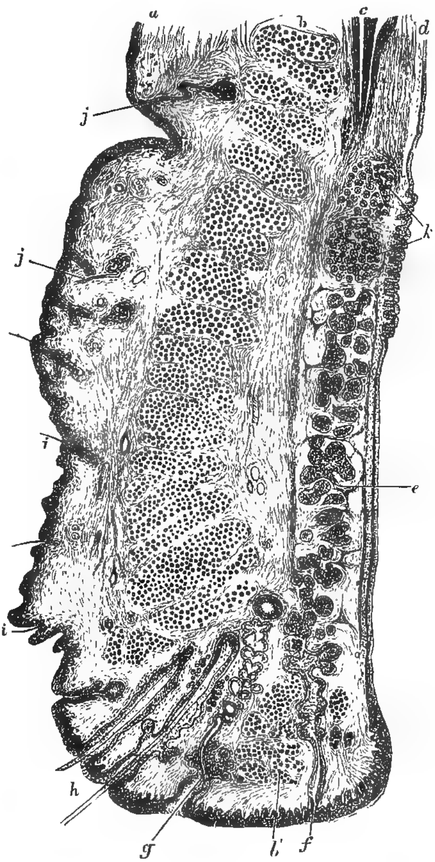

FIG. 658.—VERTICAL SECTION THROUGH THE UPPER EYELID. (Waldeyer)

a, skin; *b*, orbicularis; *b'*, ciliary bundle; *c*, involuntary muscle of eyelid; *d*, conjunctiva; *e*, tarsus with Meibomian gland; *f*, duct of the gland; *g*, sebaceous gland near eyelashes; *h*, eyelashes; *i*, small hairs in outer skin; *j*, sweat glands; *k*, posterior tarsal glands.

The **eyelids** (fig. 658) are covered externally by the skin, and internally or posteriorly by a mucous membrane, the *conjunctiva*, which is reflected from over the globe of the eye. They are composed in the main of connective tissue, which is dense and fibrous under the conjunctiva, where it forms what is known as the *tarsus*.

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[1] For the distribution of the nerve-fibres and cell-processes within the retina Golgi's silver chromate method is employed (see § 10).

[2] See Appendix. Cajal's reduced silver method may also be used.

Embedded in the tarsus is a row of long sebaceous glands (the *Meibomian glands, f*), the ducts of which open at the edge of the eyelid. The rest of the thickness of the eyelid is composed of a somewhat loose connective tissue, which contains the bundles of the *orbicularis* muscle (*b*). In the upper eyelid the *levator palpebræ* is inserted into the tarsus by a fibrous expansion; some bundles of involuntary muscle are also present near the attachment of the eyelid. The skin has the usual structure; it includes small sweat glands, and the follicles of small hairs, and, in addition, at the edge of the eyelid, the large hair-follicles from which the eyelashes grow. The epithelium of the conjunctiva palpebræ is columnar, passing at the edge of the lid into the stratified epithelium of the skin; it also becomes stratified in the part which is reflected over the globe of the eye. The nerves of the conjunctiva terminate for the most part in end-bulbs, which in man are spheroidal, and formed chiefly of a small mass of polyhedral cells; but in the calf and most animals they are elliptical.

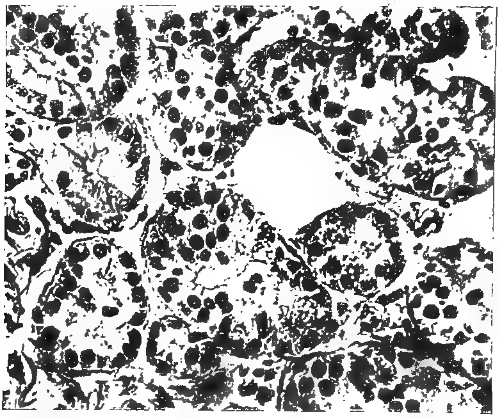

FIG. 659.—ALVEOLI OF LACRIMAL GLAND OF MAN. Photographed from a preparation by Prof. Martin Heidenhain. Magnified 200 diameters.

Some of the cells show secretion granules. In one or two situations the intercellular canaliculi which open into the lumen of the alveolus can be made out.

The **lacrimal glands** may be mentioned in connexion with the eyelid. They are compound racemose glands yielding a watery secretion. Their alveoli are lined by columnar or polyhedral cells (fig. 659), which are normally filled with granules, but, after profuse secretion, these disappear, and the cells become shorter and smaller. The ducts, of which there are several, open at the upper fold of the conjunctiva near its outer extremity.

THE SCLEROTIC AND CORNEA.

The **globe of the eye** (fig. 660) is enclosed by three coats, the cornea-sclera, choroid-iris, and retina. It is filled by the vitreous and aqueous humours and the crystalline lens which lies between them.

The **sclerotic coat** (sclera) is composed of dense fibrous tissue, the bundles of which are intimately interlaced. It is thickest at the back of the eyeball. It is covered externally with a lymphatic endothelium, while internally it is lined by a layer of connective tissue containing pigment-cells, which give it a brown appearance (*lamina fusca*). At the entrance of the optic nerve the sclerotic is prolonged into the sheath of that nerve, the bundles of which, piercing the coat, give a sieve-like aspect to the part (*lamina cribrosa*).

The **cornea** (figs. 661, 662) consists of the following layers (enumerated from before back):—

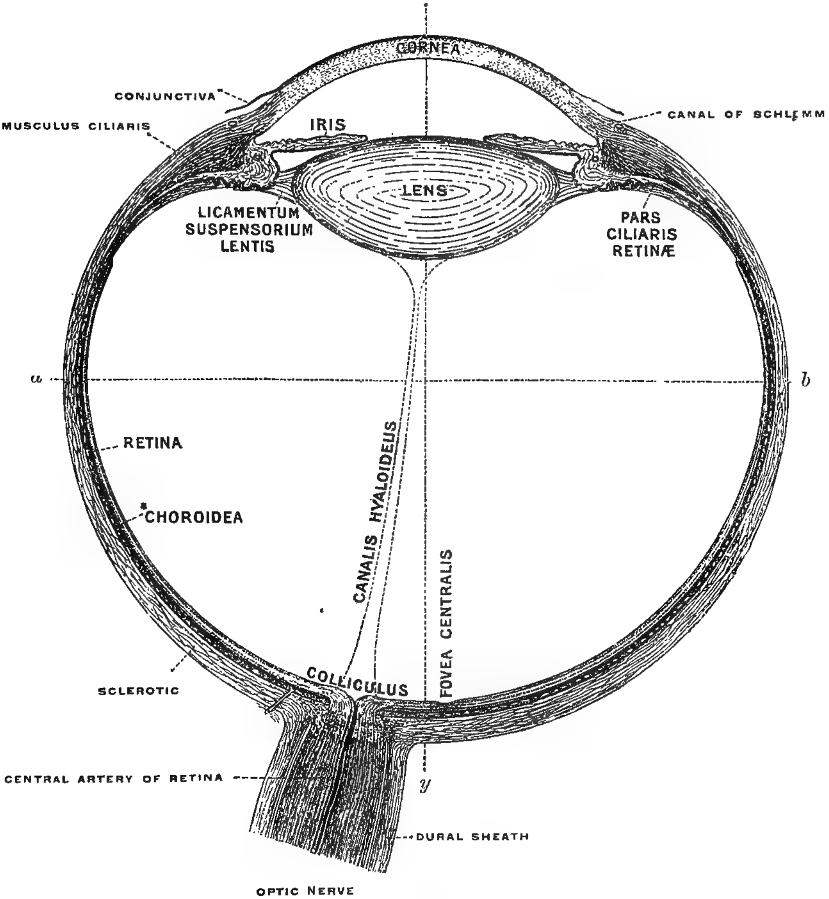

FIG. 660.—DIAGRAM OF A SECTION THROUGH THE (RIGHT) HUMAN EYE PASSING HORIZONTALLY NEARLY THROUGH THE MIDDLE. Magnified about 4 diameters.
a, *b*, equator; *x*, *y*, optic axis.

1. A *stratified epithelium* continuous with the epithelium of the conjunctiva.

2. A thin lamina of homogeneous connective tissue (*membrane of Bowman*), upon which the deepest cells of the epithelium rest.

3. A thick layer of fibrous connective tissue which forms the *proper substance* of the cornea. This is continuous laterally with the tissue of the sclerotic. It is composed of bundles of white fibres arranged in regular

laminæ, the direction of the fibres crossing one another at right angles in the alternate laminæ. Between the laminæ lie flattened connective-tissue corpuscles (fig. 663). These are branched and united by their processes into a continuous network; there is, of course, a corresponding network of cell-spaces (fig. 664). In vertical sections the cells appear narrow and spindle-shaped (fig. 661). In the superficial laminæ near the margin there are a few bundles of fibres which run obliquely towards the surface (fig. 661, *a*).

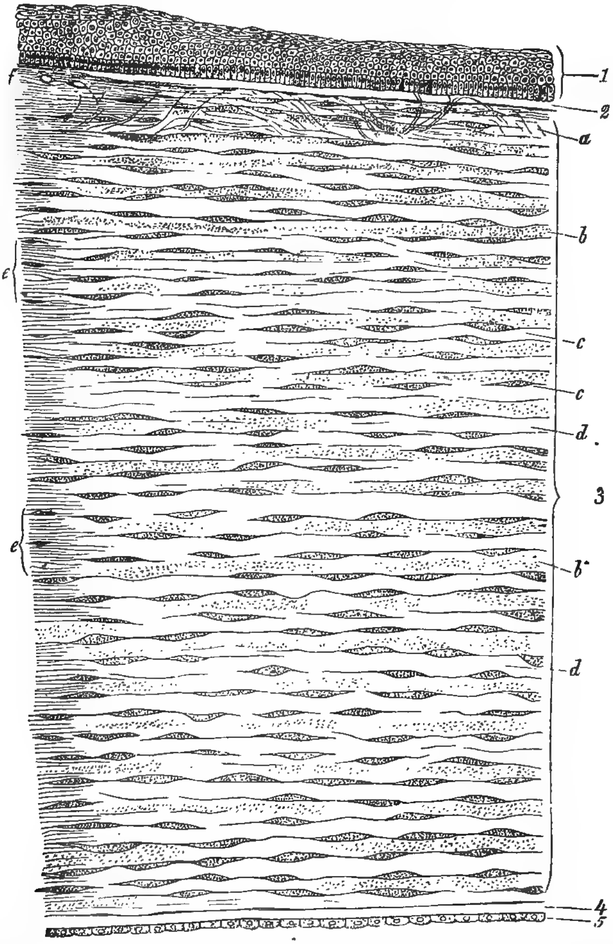

FIG. 661.—VERTICAL SECTION OF HUMAN CORNEA FROM NEAR THE MARGIN. (Waldeyer.) Magnified.

1, epithelium; *2*, anterior homogeneous lamina; *3*, substantia propria corneæ; *4*, posterior homogeneous (elastic) lamina; *5*, endothelium of the anterior chamber; *a*, oblique fibres in the anterior layer of the substantia propria; *b*, lamellæ with their fibres cut across, producing a dotted appearance; *c*, corneal corpuscles appearing fusiform in section; *d*, lamellæ with the fibres cut longitudinally; *e*, transition to the sclerotic, with more distinct fibrillation, and surmounted by a thicker epithelium; *f*, small blood-vessels cut across near the margin of the cornea.

4. A homogeneous elastic layer (*membrane of Descemet*). This completely

covers the back of the cornea, but near the angle which the cornea forms with the iris it breaks up into separate fibres (*ligamentum pectinatum*) which are partly continued into the iris as the *pillars of the iris.*

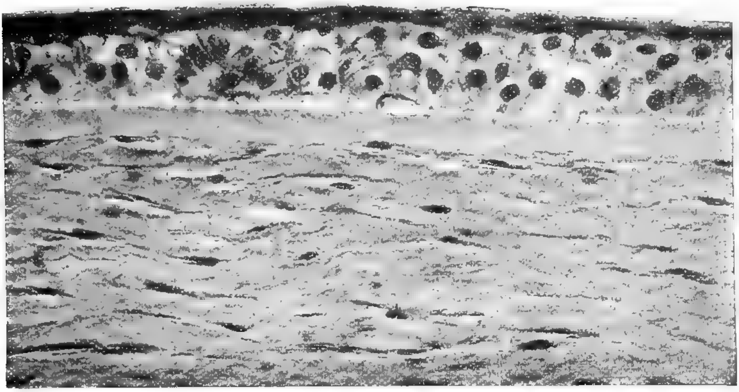

FIG. 662.—SECTION OF HUMAN CORNEA, SHOWING THE STRATIFIED EPITHELIUM, THE MEMBRANE OF BOWMAN, AND THE SUPERFICIAL LAYERS OF THE PROPRIA. Photograph. Highly magnified.

5. A layer of pavement-epithelium (*endothelium of Descemet's membrane*) covering the posterior surface of the elastic lamina, and lining the front of the anterior chamber of the eye (fig. 661, 5). At the sides it is continued over the ligamentum pectinatum into a similar endothelium covering the anterior surface of the iris. The cells of the endothelium of Descemet's membrane are separated from one another by intercellular spaces,

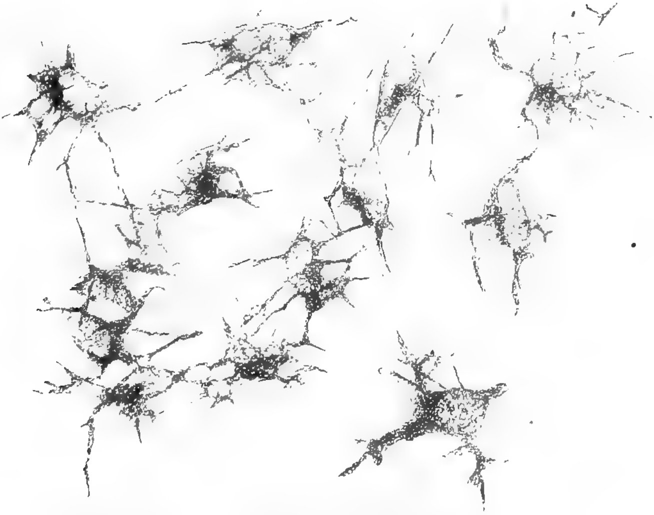

FIG. 663.—CELLS OF RABBIT'S CORNEA STAINED WITH GOLD CHLORIDE. Magnified 300 diameters.

which with suitable treatment may be seen to be bridged across by bundles of fibrils which pass through the cells (fig. 665).

The nerves of the cornea pass in from the periphery, losing their medullary sheath as they enter the corneal substance. They form a primary plexus in the substantia propria, a secondary or subepithelial plexus immediately under the epithelium which covers the anterior surface, and a terminal plexus of fine fibrils which pass from the subepithelial plexus in pencil-like tufts and become lost between the epithelium-cells (fig. 666). In some animals (*e.g.* frog) there is also a plexus of fine fibrils near the posterior surface under the endothelium of Descemet's membrane (fig. 667). There are no blood-vessels or lymphatics in the cornea, although they come close up to its margin.

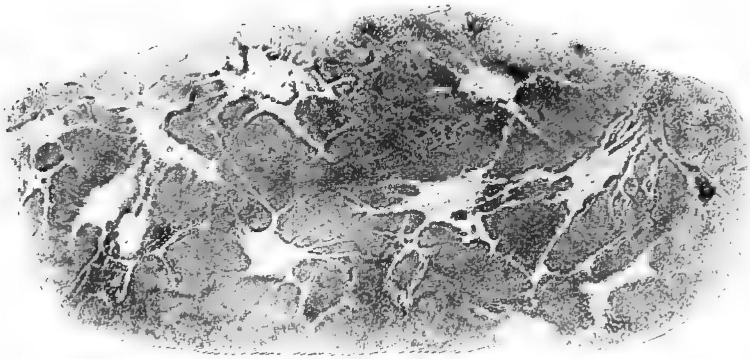

FIG. 664.—CELL SPACES OF RABBIT'S CORNEA PREPARED WITH SILVER NITRATE. Magnified 300 diameters. Photographed from a preparation by H. Pringle.

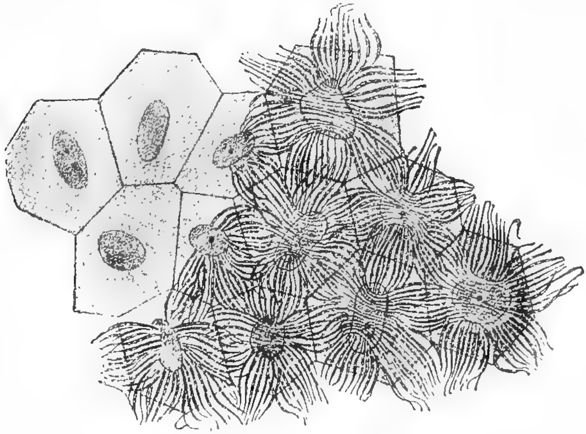

FIG. 665.—EPITHELIUM-CELLS OF DESCEMET'S MEMBRANE. (Smirnow.)

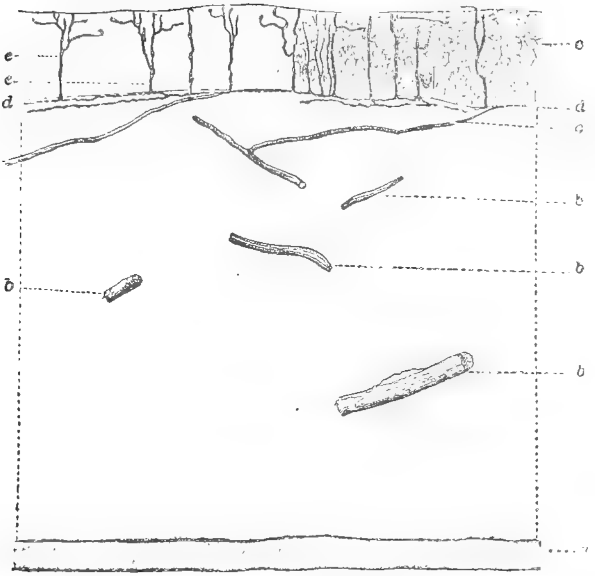

FIG. 666.—VERTICAL SECTION THROUGH THE CORNEA. (Cohnheim.)

The corneal corpuscles and the cells of Descemet's membrane are not represented; the anterior epithelium is represented only in part. *a*, Descemet's membrane; *b*, part of nerve plexus in substantia propria; *c*, branches going to the epithelium; *d*, fibres of the subepithelial layer; *e*, vertical fibrils with horizontal outrunners.

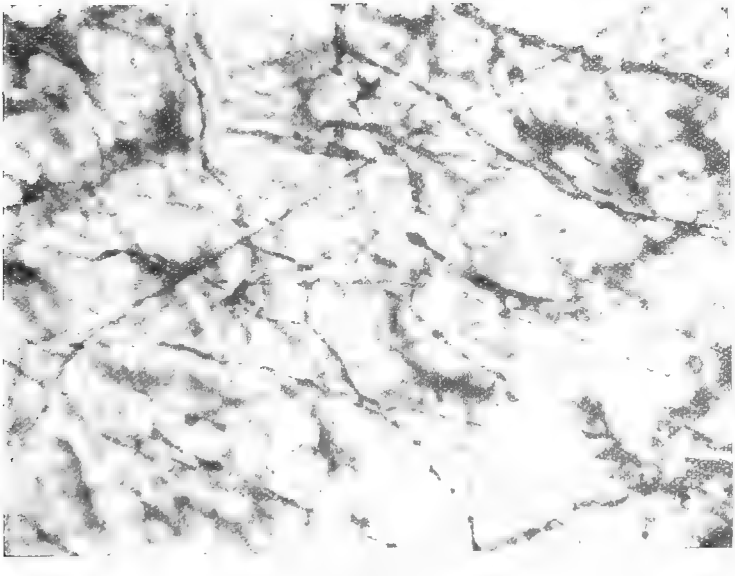

FIG. 667.—CELLS AND NERVE-FIBRILS OF POSTERIOR SURFACE OF FROG'S CORNEA. Gold preparation.

THE CHOROID AND IRIS.

The **choroid** or **vascular coat** of the eye is of a black colour in many animals, but in the human eye it is brown. It is composed of connective tissue, the cells of which are large and filled with pigment (figs. 668, 669). It contains in its inner layer a close network of blood-vessels, and in its anterior part the involuntary muscular fibres of the ciliary muscle, which pass backwards from their origin at the junction of the cornea and

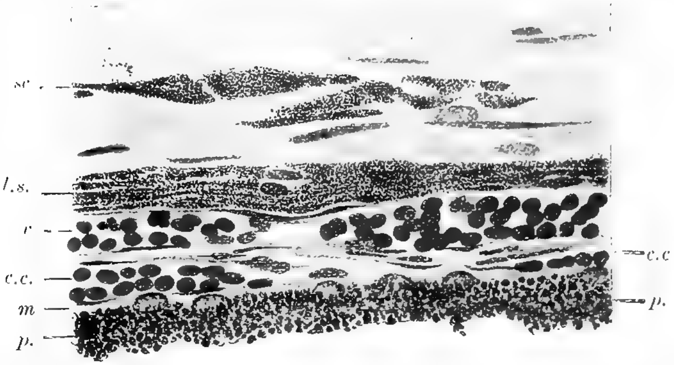

Fig. 668.—Section of choroid (man) with part of sclera. Attached to the inner surface of the choroid is a portion of the retinal pigment. Magnified 200 diameters.

sc, sclera ; *l.s.*, lamina suprachoroidea ; *r*, larger blood-vessels of choroid ; *c.c.*, chorio-capillaris ; *m*, basement-membrane (membrane of Bruch) ; *p*, portions of retinal pigment-cells.

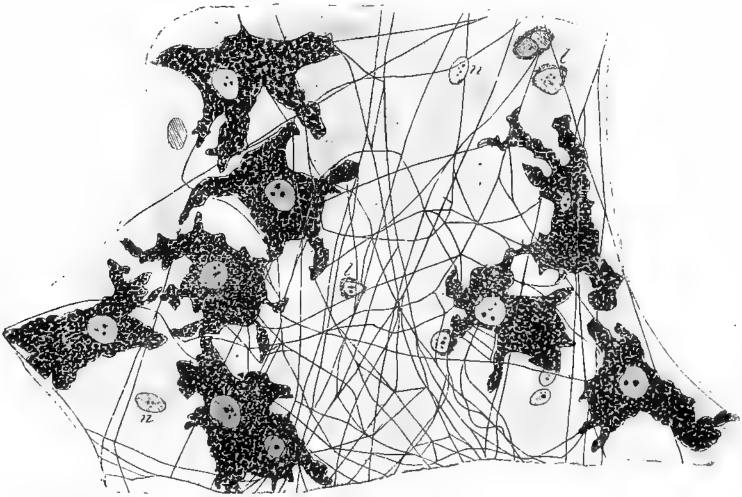

Fig. 669.—A small portion of the lamina suprachoroidea from the human eye. Highly magnified.

The branching pigment-cells and elastic fibres are well shown ; *n*, nuclei of endothelial-cells (the outlines of the cells are not indicated) ; *l*, lymph-cells.

sclerotic, to be inserted into the choroid. The choroid is separable into the following layers (enumerated from without in):—

1. The *lamina suprachoroidea* (fig. 668, *l.s.*). This is a loose membrane composed of delicate connective tissue pervaded by a network of fine elastic fibres, and containing many large branched pigment-cells and lymph-corpuscles (fig. 699). It is covered superficially by a lymphatic endothelium, and is separated from the lamina fusca of the sclerotic by a cleft-like lymph-space which is bridged across here and there by the passage of vessels and nerves, and by bands of connective tissue.

2. The *vascular layer* of the choroid (fig. 668, *v* and *c.c.*) resembles the suprachoroidea in structure, but contains the blood-vessels of the coat. In its outer part are the larger vessels (arteries and veins), the veins having a peculiar vorticose arrangement; in its inner part (choriocapillaris) are the capillaries, which form an extremely close network with elongated meshes, the capillaries radiating from the extremities of the small arteries and veins in a highly characteristic manner (fig. 670). In the ciliary processes the vessels have for the most part a longitudinal direction, but there are numerous convoluted transversely disposed capillaries uniting the longitudinal vessels (fig. 677, *d*).

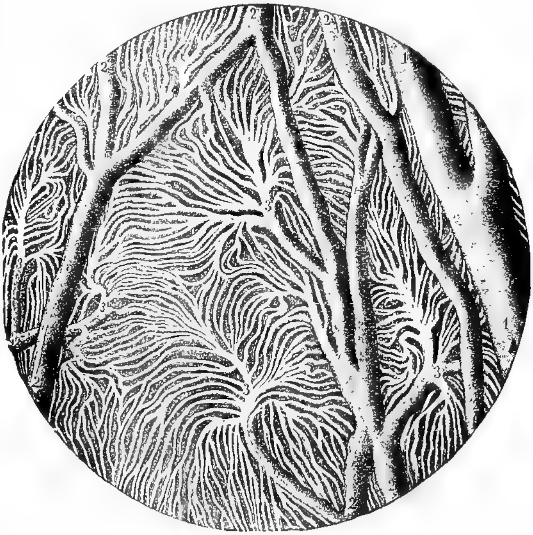

FIG. 670.—INJECTED BLOOD-VESSELS OF THE CHOROID COAT. (Sappey.)

1, one of the larger veins; 2, small anastomosing vessels; 3, branches dividing into the smallest vessels.

3. Lining the inner surface of the choroid is a thin transparent membrane known as the *membrane of Bruch* (fig. 668, *m*).

Ciliary processes.—At the front of the choroid this coat becomes thickened, partly by the appearance of radially arranged plaits or ridges (ciliary processes with intervening grooves), partly by the development of a ring of muscle (ciliary muscle) which encircles the globe at this part, lying between the sclera and choroid. The ciliary processes are formed like the rest of the choroid of highly vascular pigmented connective tissue, but, in place of retina, they are covered internally by two layers of epithelium, the outer layer being thickly pigmented (fig. 671). In the middle and anterior parts the epithelium dips down into the connective-tissue corium in the form of glandular tubes, which in all probability assist in the secretion of the aqueous humour. In order to bring these *ciliary glands* distinctly into view, it is necessary to bleach the pigment (fig. 672).

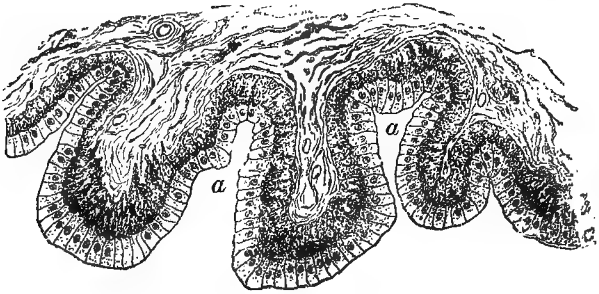

FIG. 671.—SECTION ACROSS THE POSTERIOR PART OF THREE CILIARY PROCESSES. Magnified 155 diameters. (Piersol.)

a, recesses between the ciliary processes; *b*, the deeper (pigmented) layer of epithelium; *c*, the superficial layer of non-pigmented columnar cells. These two layers of epithelium form what is termed the pars ciliaris retinæ (p. 518).

The **ciliary muscle** consists of involuntary muscular bundles which arise at the corneo-sclerotic junction, and pass meridionally backwards to be inserted in the choroid (fig. 673, *M*). Many of the deeper-seated bundles take an oblique direction, and these pass gradually into others which run circularly around the circumference of the iris, on a level with the ciliary processes. This set of circularly arranged bundles constitutes the *circular ciliary muscle* of H. Müller (*Mu*); it is most marked in hypermetropic eyes.

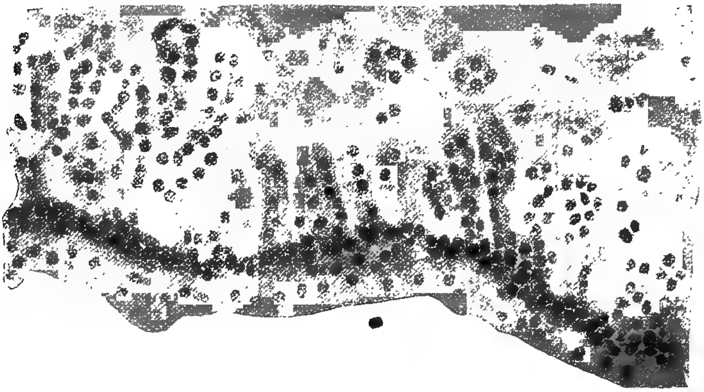

FIG. 672.—GLANDS OF THE CILIARY PROCESSES AS SEEN AFTER BLEACHING THE PIGMENT COVERING THEM. (E. Treacher Collins.)

The **iris**.—The iris is that part of the vascular coat of the eye which extends in front of the lens. It is continuous with the choroid and has a somewhat similar structure, but its pigment-cells often contain variously

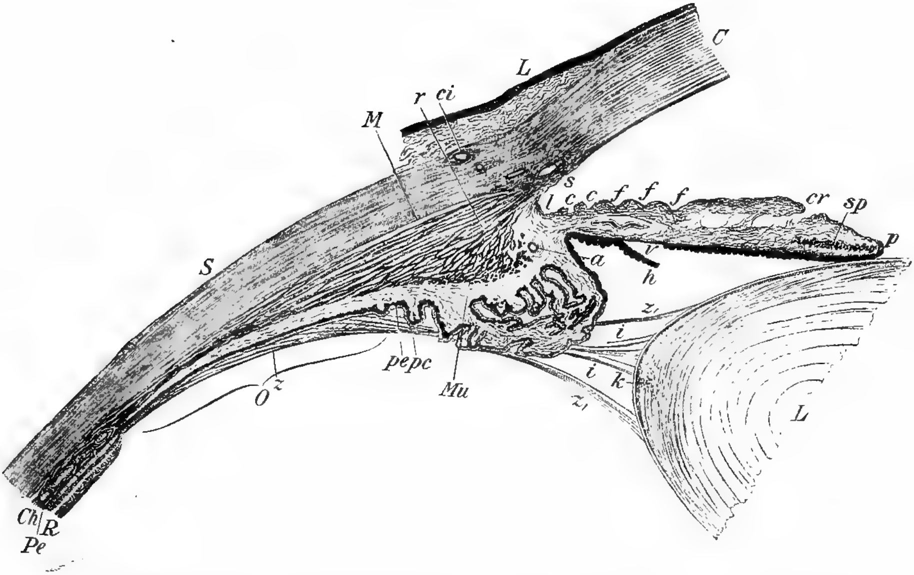

FIG. 673. SECTION THROUGH THE CILIARY PART OF THE EYE, INCLUDING PART OF THE CORNEA, THE ORA SERRATA, THE IRIS AND THE EDGE OF THE LENS WITH ITS SUSPENSORY LIGAMENT. (Fuchs.)

C, cornea; *S*, sclerotic; *Ch*, choroid; *R*, retina; *Pe*, its pigmented epithelium; *O*, pars ciliaris: this is continued over the choroid processes; *pe.*, *pc.*, pigmented and non-pigmented layers of pars ciliaris; *L*, lens; *M*, ciliary muscle; *r*, its radiating (meridional) fibres passing from their origin at the corneo-sclerotic junction; *Mu*, circular ciliary muscle; *ci*, artery of sclerotic; *s*, vein (canal of Schlemm); *z*, fibres of zonula of Zinn passing between choroid processes into the suspensory ligament of the lens (*z'*, *i*); *l*, angle of anterior chamber; *sp*, sphincter pupillæ; *p*, edge of pupil; *h*, pigmented epithelium of iris (accidentally detached at this point and showing, *v*, layer of dilatator pupillæ); *c*, *c*, *f*, *f*, creases and folds of anterior surface of iris; *cr*, a fissure in this surface (accidental); *a*, artery at insertion of iris; *k*, capsule of lens.

coloured pigment. Besides the delicate connective tissue with numerous elastic fibres and blood-vessels of which it is chiefly composed, it contains two sets of plain muscular fibres. The one set forms the *sphincter pupillæ* (figs. 673, *sp.*; 674, *a*), which encircles the pupil; the other set consists of a flattened layer of radiating fibres which extend from the attachment of the iris nearly to the pupil, lying close to the posterior surface and constituting the *dilatator pupillæ* (figs. 674, *b*; 675 and 676).

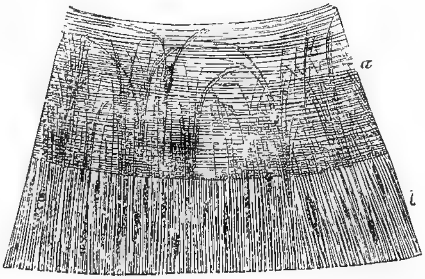

FIG. 674.—SEGMENT OF THE IRIS, SEEN FROM THE POSTERIOR SURFACE AFTER REMOVAL OF THE UVEAL PIGMENT. (Iwanoff.)

a, sphincter muscle; *b*, dilatator muscle of the pupil.

The back of the iris is covered by a thick double layer of pigmented epithelium (uvea) (fig. 676) continuous with the epithelium of the pars ciliaris retinæ (p. 518).

The blood-vessels of the iris (fig. 677, *e*) converge towards the pupil. Near the pupil the small arteries form an anastomotic circle, from which capillaries arise and pass still nearer the pupil, around which they form a close capillary network.

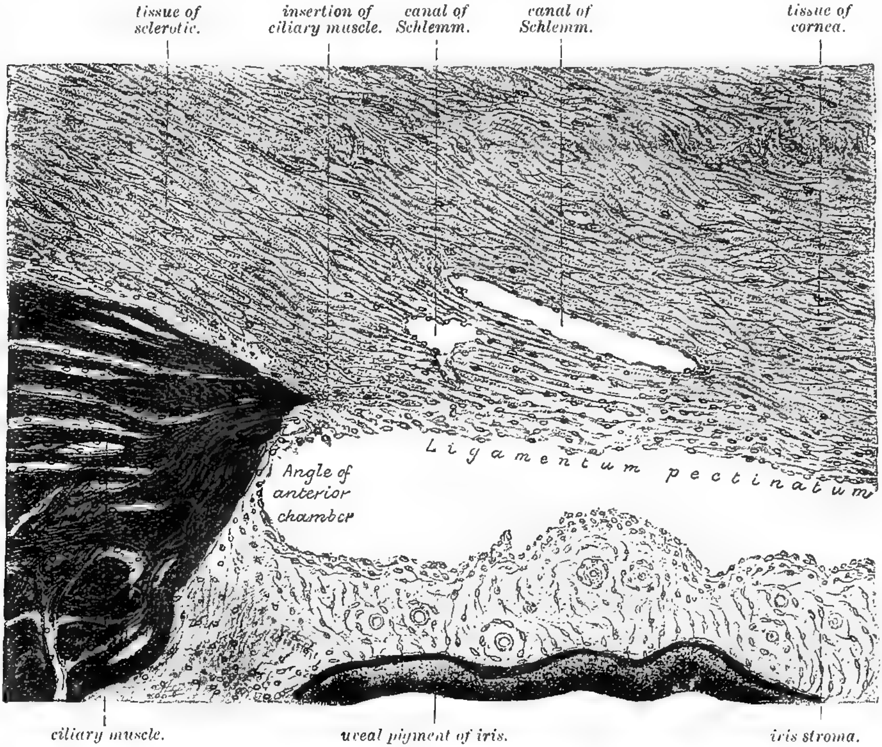

FIG. 675. SECTION (FROM THE EYE OF A MAN), SHOWING THE RELATIONS OF THE CILIARY MUSCLE TO THE SCLEROTIC, THE IRIS, AND THE CAVERNOUS SPACES NEAR THE ANGLE OF THE ANTERIOR CHAMBER.

The figure, which is copied from a photograph, includes a small portion of the ciliary muscle, the fibres of which are seen to be converging to a point immediately anterior to the angle of the anterior chamber. Here they are attached through the medium of a band of the fibrous tissue of the sclerotic (consisting mainly of circular bundles) to the outer part of the ligamentum pectinatum, which forms a loose tissue with open meshes lying between the canal of Schlemm and the anterior chamber. In the right half of the figure the fibres of the ligamentum pectinatum are seen to be gradually converging towards the posterior surface of the cornea, and somewhat beyond the part shown in this figure they merge into the membrane of Descemet. A communication of the canal of Schlemm, which is double in this section, with the endothelium-lined spaces of the ligamentum pectinatum, is apparent, and also communications between the last-named spaces and the anterior chamber.

A large number of nerve-fibres are distributed to the choroid and iris, chiefly to the muscular tissue of those parts (ciliary muscle and sphincter and dilatator pupillæ).

The muscular tissue of the iris is developed from the epithelium at the back of the iris (Nussbaum, Szili).

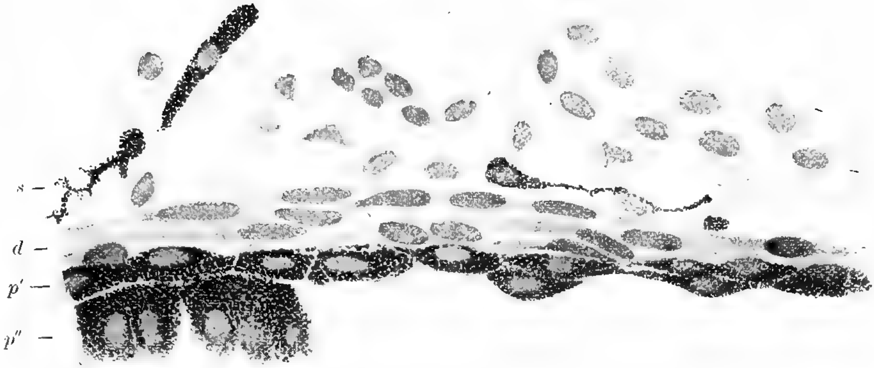

FIG. 676. SECTION OF POSTERIOR LAYERS OF HUMAN IRIS, NEAR ITS ATTACHMENT TO THE CHOROID. Magnified 600 diameters.

s, iris stroma, with connective tissue, branched pigment-cells, and blood-vessels; *d*, dilatator muscle; *p'*, deeper layer of uveal pigment; *p''*, superficial layer of uveal pigment; this layer is broken away from the larger part of the section.

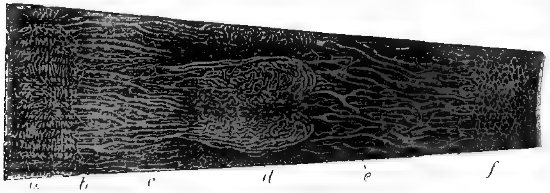

FIG. 677.—VESSELS OF THE CHOROID, CILIARY PROCESSES AND IRIS OF A CHILD. (Arnold.) 10 diameters.

a, capillary network of the posterior part of the choroid, ending at *b*, the ora serrata; *c*, arteries of the corona ciliaris, supplying the ciliary processes, *d*, and passing into the iris, *e*; *f*, the capillary network close to the papillary margin of the iris.

THE RETINA.

The **retina** consists of the eight layers shown in the accompanying diagram (fig. 678), numbered as they occur from within out.

The inner surface of the retina rests upon the hyaloid membrane of the vitreous humour. It is formed of the united bases of the fibres of Müller, which will be afterwards described.

The *layer of nerve-fibres* is formed by the expansion of the optic nerve after it has passed through the coats of the eye (fig. 679). The optic nerve differs from other cerebro-spinal nerves in being made up not of separate cylindrical bundles or funiculi, but of one large bundle, covered with a thick sheath and subdivided by numerous interlacing septa into portions of irregular size and shape (fig. 680). A section across the nerve taken near its entrance into the globe shows a central strand of connective tissue containing the central retinal artery and vein which pass obliquely into the nerve a few millimeters from the back of the eyeball. The sheath of the nerve has a composite structure, being formed externally of a thick fibrous membrane continuous proximally with the dura mater and distally with the sclera, internally of a membrane continuous proximally with the pia mater, whilst between the two is a space containing a prolongation of the arachnoid; the space itself is continuous with the subdural and subarachnoid spaces of the cranial cavity. The nervous tissue is greatly diminished at the lamina cribrosa owing to the disappearance of the medullary sheath of the nerve-fibres, which are continued into the retina as axis-cylinders only.

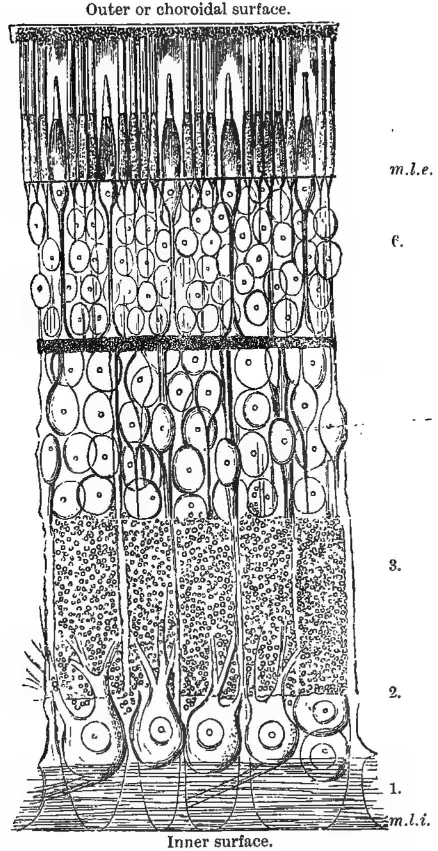

FIG. 678.—DIAGRAMMATIC SECTION OF THE HUMAN RETINA. (M. Schultze.)

1, Layer of optic nerve-fibres; 2, layer of optic nerve-cells; 3, inner synapse or molecular layer; 4, layer of inner granules or bipolars; 5, outer synapse or molecular layer; 6, layer of outer granules (outer nuclear layer); 7, layer of rods and cones; 8, layer of pigment-cells; *m.l.i.*, membrana limitans interna; *m.l.e.*, membrana limitans externa.

At its entrance the nerve forms a slight eminence (*colliculus nervi optici*). The nerve-fibres lose their medullary sheath on reaching the retina. Most are connected with (derived from) the cells of the ganglionic or optic nerve-cell layer (fig. 681), but some (centrifugal) fibres pass through the ganglionic and molecular layers to form a terminal arborisation in the inner nuclear layer (fig. 681, *i*, *j*, *m*, and fig. 682). The layer of nerve fibres becomes gradually thinner towards the anterior part of the retina.

The *layer of optic nerve-cells*, or *ganglionic layer*, is composed of nerve-cells somewhat like the cells of Purkinje of the cerebellum. They vary in size, although those of large size are prevalent in most parts of the retina. In the yellow spot, on the other hand, smaller nerve-cells are met with, and they may here lie several deep. The cells have a fine axis-cylinder process prolonged into a fibre of the layer of optic nerve-fibres and a thick branching process, the ramifications of which terminate in the inner synapse layer in flattened arborisations at different levels (fig. 683, A, B, C).

The *inner synapse layer* (*inner molecular layer*) is comparatively thick. It has an appearance very like parts of the grey matter of the nerve-centres. A few small cells are scattered through it, but it is mainly occupied by the processes of the optic nerve-cells and of the inner granules which form synapses within it; it is also traversed by centrifugal fibres from the optic nerve layer, as well as by the fibres of Müller.

The *layer of inner granules* (also termed *inner nuclear layer*) is mainly composed of bipolar nerve-cells containing large nuclei. One process (the axon) of each of these cells (fig. 681) extends inwards into the inner molecular layer where it spreads out into a terminal arborisation. These arborisations occur at different levels in the layer, forming synapses with the optic nerve-cells. Another process (dendron) is directed outwards, and arborises in the outer molecular layer, where it forms synapses with the terminations of the rod- and cone-fibres. It has been shown by Ramón y Cajal that there are two kinds of bipolars, one kind (*rod-bipolars*, fig. 681, *cd*) being connected externally with the rods of the retina, and passing inwards to ramify over the bodies of the nerve-cells; whilst the others (*cone-bipolars*, *e*) are connected with the cone-fibres, and ramify in the middle of the inner molecular layer. The outwardly directed processes of the cone-bipolars are, in some animals, but not in mammals, continued as far as the external limiting membrane, where each ends in a free extremity (*fibre of Landolt*, fig. 684, E). Besides these bipolar nerve-cells, there are other larger inner granules (spongioblasts of some authors) which

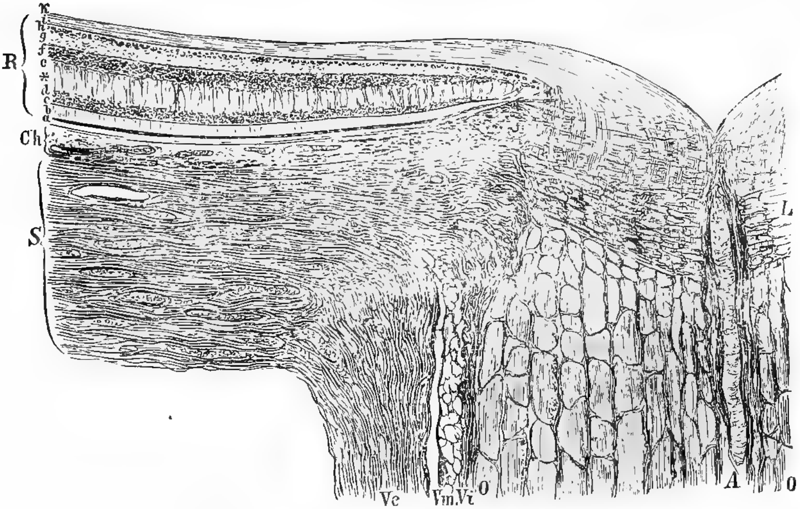

FIG. 679.—SECTION THROUGH THE COATS OF THE EYEBALL AT THE ENTRANCE OF THE OPTIC NERVE. (Toldt.)

Ve, dural sheath; *Vm*, arachnoidal sheath, and *Vi*, pia-matral sheath of the optic nerve, with lymph spaces between them; *O*, *O*, nerve bundles; *L*, lamina cribrosa; *A*, central artery; *S*, sclerotic; ***Ch***, choroid; *R*, retina. The small letters refer to the various parts of the retina, *b* being the layer of rods and cones, ✲ rod- and cone-fibres, ***i*** optic nerve-fibres, and *k* the hyaloid membrane of the vitreous humour.

are different in character, having ramified processes which extend into the inner molecular layer (figs. 681, *h*; 684, A, B, C), in which also their bodies are often partly embedded. The cells in question have been regarded as of the nature of neuroglia-cells, but according to Cajal they are probably nerve-cells. He termed them *amacrine-cells*, since he believed them to be destitute of a long process; but some of the amacrine-cells have since been noticed to give off, besides the branching processes or dendrons, which ramify in the molecular layer, an axis-cylinder process extending into the nerve-fibre layer. There are also certain cells in the outer part of the granule layer which send their processes entirely into the outer molecular layer (fig. 684, H). These are the *horizontal cells* of Cajal (spongioblasts of outer molecular layer of some authors). The fibres of Müller have nucleated enlargements (fig. 684, J) amongst the bipolars of this layer.

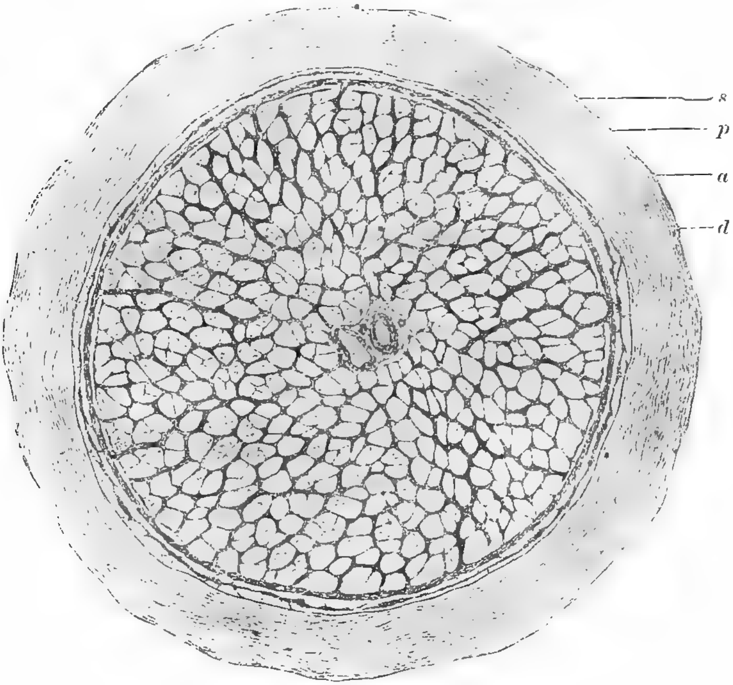

FIG. 680.—SECTION OF OPTIC NERVE: MAN. (Greeff.) Magnified 24 diameters.

The section is taken near the junction with the globe. *d*, sheath derived from dura; *a*, sheath from arachnoid; *p*, from pia mater; *s*, a layer of superficial neuroglia.

The *outer molecular layer* is thin, and is composed mainly of the arborisations of the inner granules and of the rod- and cone-fibres, as well as of the horizontal cells (figs. 681, 684), which all form synapses in this layer.

The *outer nuclear layer* and the *layer of rods and cones* are composed of elements which are continuous through the two layers, and they should properly, therefore, be described as one. It has been termed the ***sensory epithelium of the retina*** (fig. 685, 6 and 7). The elements of which this nerve-epithelium consists are elongated cells of two kinds. The most

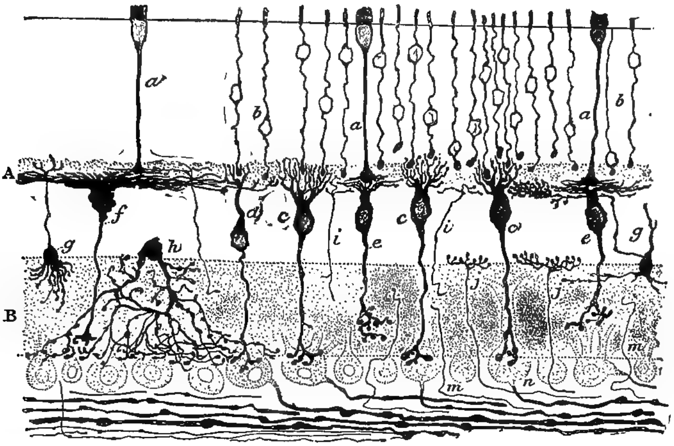

FIG. 681.—SECTION OF DOG'S RETINA, GOLGI METHOD. (Cajal.)

a, cone-fibre; *b*, rod-fibre and nucleus; *c*, *d*, bipolar cells (inner granules) with vertical ramifications of their outer processes or dendrons: in the centre of the ramification lie the enlarged ends of rod-fibres; *e*, other bipolars with flattened ramifications abutting against ramified ends of cone-fibres; *f*, large bipolar with flattened ramification; *g*, inner granule-cell sending an axon towards the rod- and cone-fibres; *h*, amacrine cell with diffuse arborisation of its processes in inner molecular layer; *i*, *j*, *m*, centrifugally conducting nerve-fibrils passing respectively to outer molecular, inner nuclear, and inner molecular layers; *n*, ganglionic cells with axons passing into nerve-fibre layer; A, outer molecular layer; B, inner molecular layer..

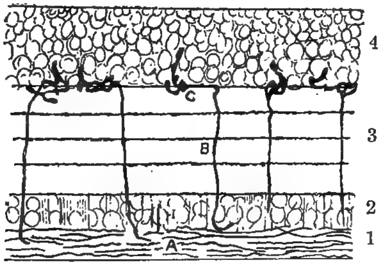

FIG. 682.—SECTION THROUGH THE INNER LAYERS OF THE RETINA OF A BIRD, PREPARED BY GOLGI'S METHOD. (Cajal.)

A, nerve-fibres of optic nerve layer; B, some of these fibres passing through the inner molecular layer to end in an arborisation at the junction of the inner molecular and inner nuclear layers. The layers in this and in the two succeeding cuts are numbered in correspondence with the layers in fig. 678.

numerous, which may be termed the *rod-elements*, consist of peculiar rod-like structures (*retinal rods*) set closely side by side, each of which is prolonged internally into a fine varicose fibre (*rod-fibre*) which swells out at one part of its course into a nucleated enlargement, and ultimately ends (in mammals) in a minute knob within the outer molecular layer, where it is embedded in the ramifications of the dendrons of the rod-bipolars. The rod consists of two segments, an outer cylindrical and transversely striated segment which during life has a purplish-red colour if the eye has not been recently exposed to light, and an inner, slightly bulged segment which in part of its length is longitudinally striated. The nucleus of the rod-element in some animals, but according to Flemming not in man, has a transversely shaded aspect in the fresh condition (fig. 685). The *cone-elements* are formed of a conical tapering external part, the *retinal cone*, which is directly prolonged into a nucleated enlargement, from the farther side of which the *cone-fibre*, considerably thicker (in mammals) than the rod-fibre, passes inwards, to terminate by an expanded arborisation in the outer molecular layer; here it

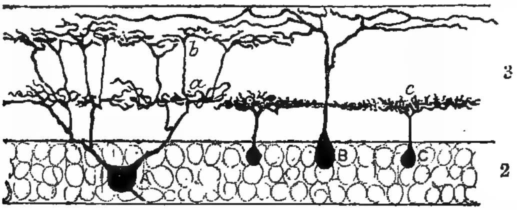

FIG. 683.—SECTION ACROSS THE MOLECULAR AND GANGLIONIC LAYERS OF A BIRD'S RETINA, PREPARED BY GOLGI'S METHOD. (Cajal.)

Three or four ganglionic cells, A, B, C, and the terminal arborisations of their dendrons, *a*, *b*, *c*, in the molecular layer, are shown.

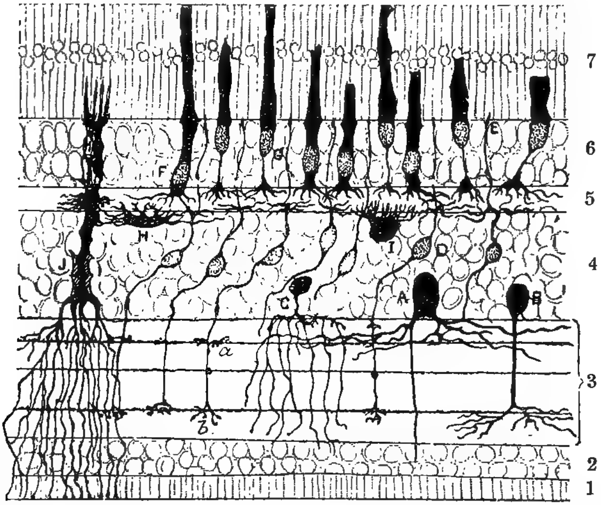

FIG. 684.—SECTION OF A BIRD'S RETINA, PREPARED BY GOLGI'S METHOD. (Cajal.)

A, large (amacrine) cell of inner nuclear layer; B, C, smaller amacrine cells; D, small bipolar nerve-cells with the one process ramifying in the inner molecular layer, and the other one ramifying in the outer molecular layer and extending (E) as far as the rods and cones as a fibre of Landolt; F, G, rod- and cone-nuclei respectively; H, I, cells with dendrons ramifying in outer molecular layer; J, fibre of Müller.

comes into relation with a similar arborisation of the dendrons of a cone-bipolar. The cone, like the rod, is formed of two segments, the outer of which, much the smaller, is transversely striated; the inner, bulged segment being longitudinally marked. The inner ends of the rod- and cone-fibres, as already stated, form synapses with the peripheral arborisations of the bipolars, and through the latter elements and their synapses in the inner molecular layer a connexion is brought about with the nerve-cells and nerve-fibres of the innermost layers.

The connexion of the retinal elements with one another and through the optic fibres with the central nervous system (anterior corpora quadrigemina and lateral geniculate bodies) is shown diagrammatically in fig. 686.

In birds, reptiles, and amphibia a small oil-globule, often brightly coloured red, yellow, or green, is found in the inner segment of each cone. Many other variations of structure are met with in different animals.

The cones are most numerous at the back of the retina; they are fewer in number, and the rods are proportionally more numerous towards the anterior part.

The *pigmentary layer* forms the most external part of the retina. It consists of hexagonal epithelium-cells (fig. 687), which are smooth externally where they rest against the choroid, but are prolonged internally into fine filaments which extend between the rods. The pigment-granules, many of which are in the form of minute crystals, lie in the inner part of the cell, but after prolonged exposure to light they are found extending along the cell-processes between the rods (Kühne), their function being probably connected with the restoration of the purple colouring matter which has been bleached by the light. This extension of the pigment is accompanied by a shortening of the cones (Engelmann) (fig. 688).

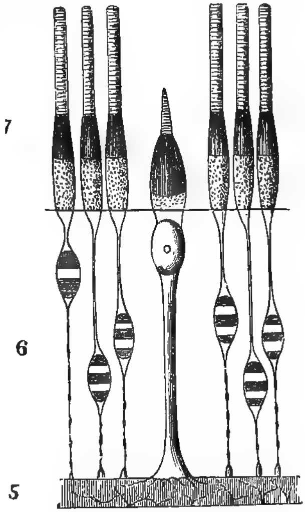

Fig. 685.—Diagrammatic representation of the rod- and cone-elements of the retina. (After Schwalbe.)

The designation of the numbers is the same as in fig. 678.

Fibres of Müller.—The fibres of Müller (fig. 684, J, and fig. 689) are long cells which pass through several of the retinal layers. Commencing at the inner surface of the retina by expanded bases which unite with one another to form the so-called internal limiting membrane (fig. 690), they pass through all the layers in succession, until they reach the outer granule layer. Here they branch and expand into a sort of honeycomb tissue which serves to support the fibres and nuclei of the rod- and cone-elements. At the bases of the rods and cones this sustentacular tissue ceases, being here bounded by a distinct margin which has been called the external limiting membrane (fig. 689, *m.l.e.*), but delicate sheaths pass from it around the bases of the rods and cones. Each **Müllerian fibre**, as it passes through the inner granule layer, has a nucleated enlargement (*b*), indicating the cell-nature of the fibre. The fibres of Müller represent ependyma-cells or long neuroglia-cells such as are found in some parts of the nerve-centres.

There are two parts of the retina which call for special description.

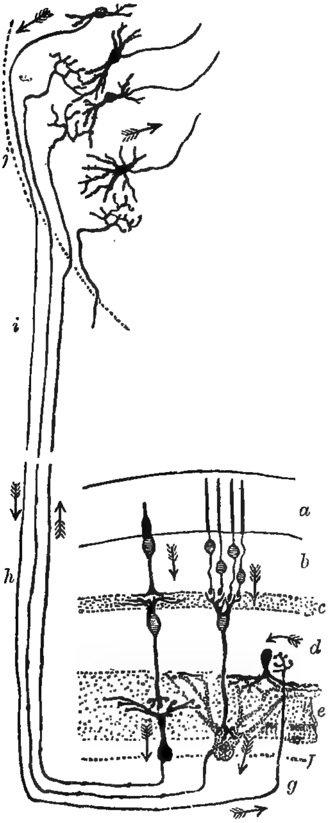

FIG. 686.—DIAGRAM OF THE CONNEXIONS OF THE RETINAL ELEMENTS WITH ONE ANOTHER AND WITH THE CENTRAL NERVOUS SYSTEM. (Cajal.)

to *g*, layers of retina; *a*, rods and cones; *b*, outer nuclear layer; *c*, outer molecular layer; *d*, inner nuclear layer; *e*, inner molecular layer; *f*, nerve-cells giving origin to fibres of optic nerve; *g*, *h*, *i*, a centrifugally conducting fibre, with a terminal arborescence in the retina; *j*, grey matter of corpus quadrigeminum.

The **macula lutea (yellow spot)**, with its **central fovea**, is the part of the retina which is immediately concerned with direct vision. It is characterised, firstly, by its greater thickness (except at the middle of the fovea); secondly, by the large number of its ganglion-cells, which are relatively small; and thirdly, by the number of cones it contains as compared with the rods. In the central fovea itself (figs. 691, 692) there are no rods, and the cones are very long and slender, measuring not more than 2μ in diameter; all the other layers become gradually thinned down almost to complete disappearance, so that the middle of the central fovea is the thinnest part of the retina. Since there are few rods, the outer granule layer loses in great measure its appearance of being composed of closely packed nuclei, and the cone-fibres are very distinct, forming the so-called *fibrous layer*. Except at the very centre the direction of these fibres is oblique in this part of the retina.

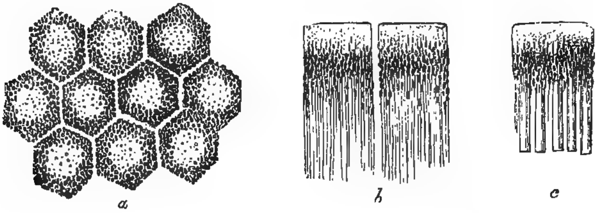

FIG. 687.—PIGMENTED EPITHELIUM OF THE HUMAN RETINA. (M. Schultze.) Highly magnified.

a, cells seen from the outer surface with clear lines of intercellular substance between; *b*, two cells seen in profile with fine offsets extending inwards; *c*, a cell still in connexion with the outer ends of the rods.

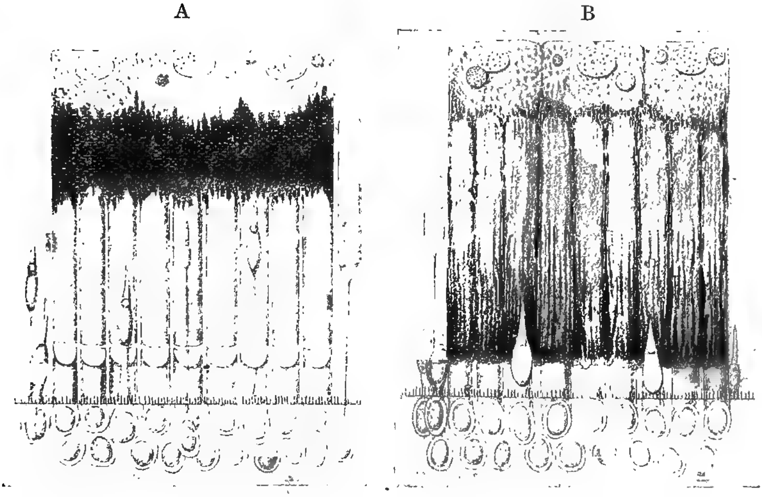

FIG. 688.—A. PART OF A SECTION OF THE RETINA FROM THE EYE OF A FROG WHICH HAD BEEN KEPT IN THE DARK FOR SOME HOURS BEFORE DEATH. (V. Genderen-Stort.)

The pigment is collected towards the outer ends of the rods, which were red, except the outer detached rod, which was green. The cones, which in the frog are much smaller than the rods, are mostly elongated.

B. A SIMILAR SECTION FROM A FROG WHICH HAD BEEN EXPOSED TO LIGHT.

The pigment is extended between the rods, and is accumulated near their bases. The rods were colourless. All the cones are contracted.

The pigmentary layer is thickened over the fovea, and there is also a thickening in the choroid coat here, due to a large accumulation of capillary vessels.

The **pars ciliaris retinæ**, which commences at the *ora serrata*, where the retina proper abruptly ends (fig. 693), is composed of two epithelial layers without nervous structures. Of the two layers, the external is a thick stratum of pigmented epithelium formed of rounded cells and continuous with the pigmentary layer of the retina on the one hand, and

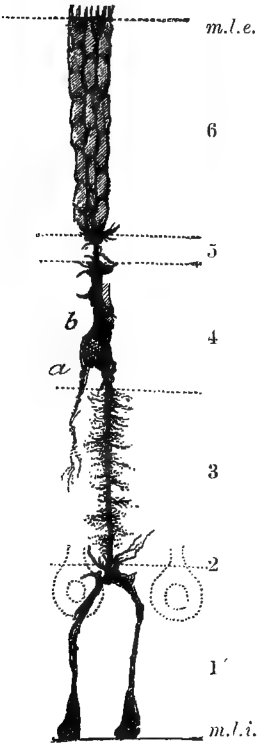

FIG. 689.—A FIBRE OF MÜLLER FROM THE DOG'S RETINA, GOLGI METHOD. (Cajal.)

1, nerve-fibre layer; 2, nerve-cell layer; 3, inner molecular layer; 4, inner granule layer; 5, outer molecular layer; 6, outer granule layer; *b*, nucleus of the fibre; *a*, a process extending into inner molecular layer; *m.l.i.*, membrana limitans interna; *m.l.e.*, membrana limitans externa.

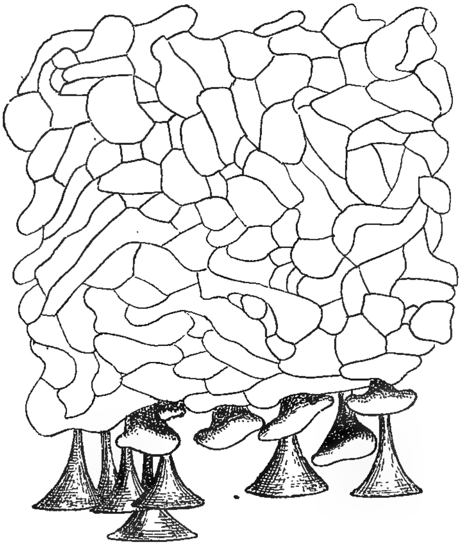

FIG. 690.—INTERNAL LIMITING MEMBRANE OF RETINA TREATED WITH SILVER NITRATE, SHOWING THE OUTLINES OF THE BASES OF THE FIBRES OF MÜLLER. (G. Retzius.)

with the uvea of the iris on the other; the inner is a layer of columnar cells (fig. 671; fig. 693, *a*, *k*).

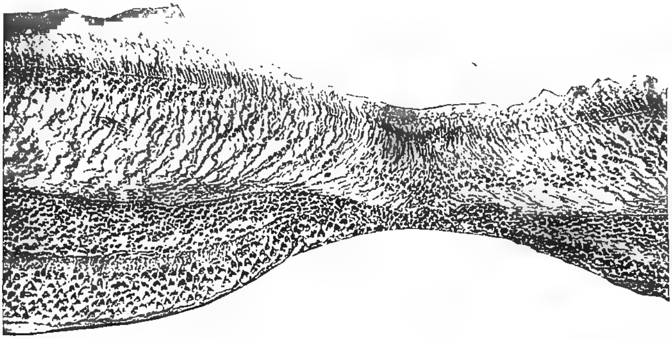

Fig. 691.—Section through the central part of the fovea centralis. Magnified 200 diameters. (From a preparation by C. H. Golding-Bird.)

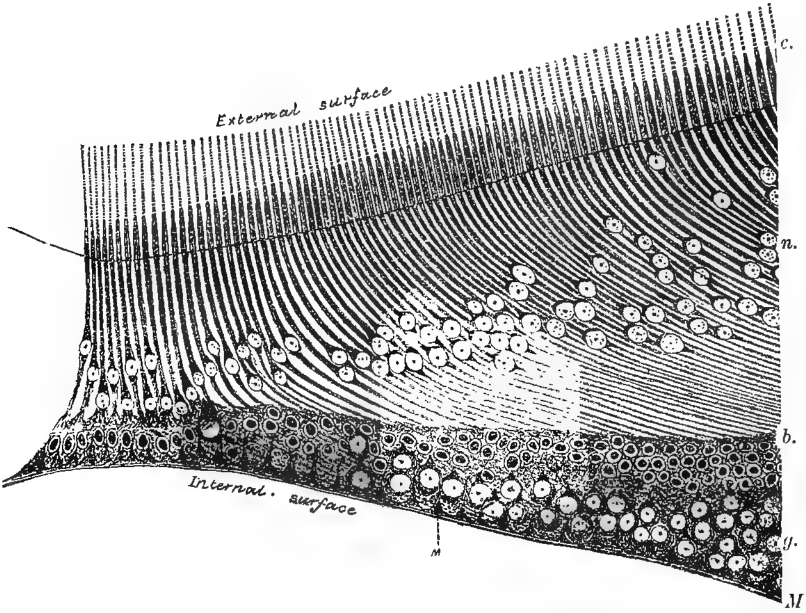

Fig. 692.—Diagram of the arrangement of the retinal elements at the central fovea.

M, bases of Müllerian fibres; *g*, ganglion-cells; *b*, nuclei of inner granules (bipolars); *n*, cone-fibre nuclei; *c*, cones.

Vessels of the retina.—The retina contains relatively few blood-vessels. The central artery enters and the vein leaves it in the middle of the optic nerve. The larger vessels ramify in the nerve-fibre layer. There are capillary networks in this layer and in the inner nuclear layer with perivascular lymph spaces around the veins and capillaries. The sensory epithelium receives no blood-vessels, it is nourished from the vessels of the choroid.

THE LENS AND VITREOUS HUMOUR.

The lens.—The lens is a laminated fibrous body enclosed by a transparent elastic capsule to which, around the circumference, the fibres of the suspensory ligament are attached (fig. 673). Immediately within the capsule, in front and at the sides, there is a layer of cubical epithelium termed the epithelium of the capsule, but at the margin of the lens the cells become longer and pass by a gradual transition into the lens-fibres (fig. 694). The *fibres* which compose the lens are long and riband-shaped, with finely serrated edges (fig. 695, A); their transverse sections are prismatic (B). Many of the superficial fibres are nucleated (C), the lens-fibres having originally been developed by the elongation of epithelium-cells.

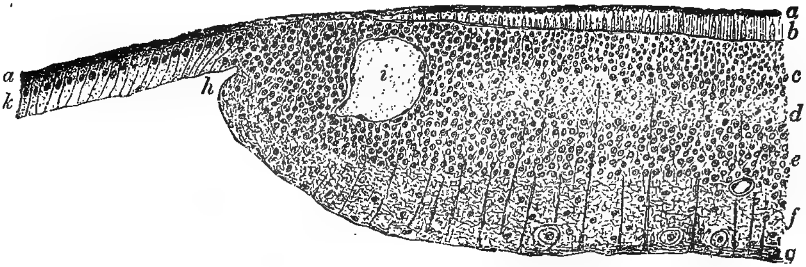

FIG. 693.—SECTION OF HUMAN RETINA AT ORA SERRATA, SHOWING THE ABRUPT TERMINATION OF THE USUAL RETINAL LAYERS AND THE CONTINUATION OF THE RETINAL SHEET AS TWO LAYERS OF CELLS, WHICH FORM THE PARS CILIARIS RETINÆ. (Piersol.)

a, *a*, pigment layer; *b*, rod- and cone-layer; *c*, outer nuclear layer; *d*, outer molecular layer; *e*, inner nuclear layer; *f*, inner molecular layer; *g*, ganglion-cell and nerve-fibre layers; *h*, section at transition line; *k*, columnar cells of pars ciliaris; *i*, a cyst (such cysts occur occasionally here).

The vitreous humour.—This is composed of soft gelatinous tissue, apparently structureless when examined in the fresh condition, but containing fibres and a few scattered cells, the processes of which are often long and varicose, and the cell-bodies distended by large vacuoles. The *hyaloid membrane*, which invests the vitreous humour, is homogeneous and structureless except in the region of the ciliary processes, where it is fibrous in structure, forming the zonule of Zinn and spreading out into the suspensory ligament of the lens (fig. 673). This part of the hyaloid membrane is connected with an annular fibrous portion of the vitreous humour which serves to give additional firmness to the attachment of the fibres of the suspensory ligament of the lens (Anderson Stuart).

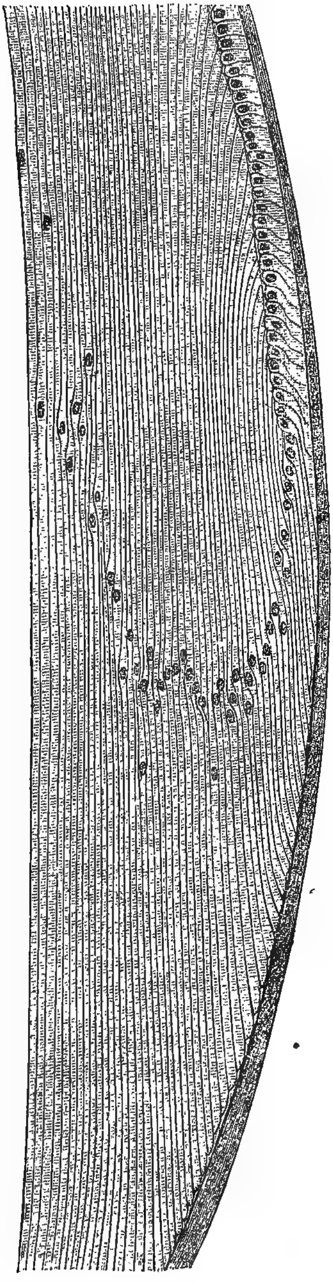

FIG. 694.—SECTION THROUGH THE MARGIN OF THE RABBIT'S LENS, SHOWING THE TRANSITION OF THE EPITHELIUM OF THE CAPSULE INTO LENS-FIBRES. (Babuchin.)

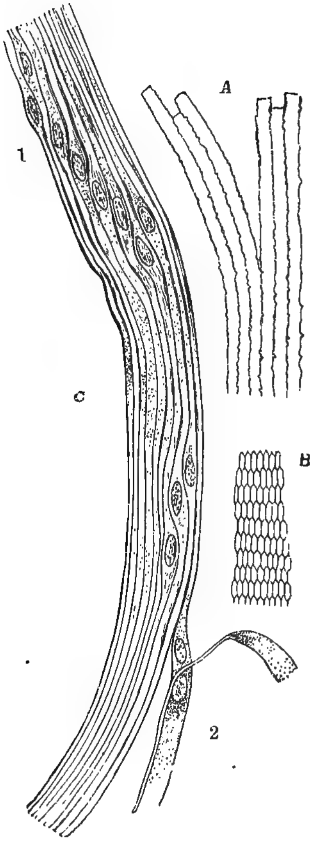

FIG. 695.—FIBRES OF THE CRYSTALLINE LENS. 350 diameters.

A, longitudinal view of the fibres of the lens of the ox, showing the serrated edges. B, transverse section of the fibres of the lens of the human eye. C, longitudinal view of a few of the fibres from the equatorial region of the human lens. Most of the fibres in C are seen edgewise, and, towards 1, present the swellings and nuclei of the "nuclear zone"; at 2, the flattened sides of two fibres are seen. (A and B from Kölliker; C from Henle.)

LESSONS XLIX. AND L.

THE NOSE AND EAR.

1. VERTICAL sections of the nasal mucous membrane. The sections may be carried either across the upper turbinate bone, after decalcification, or across the upper part of the nasal septum. Make a sketch under the low power. Notice the difference in the character of the epithelium in the olfactory and respiratory parts of the membrane.

2. Teased preparation of the epithelium of the olfactory mucous membrane. A piece of the membrane is placed quite fresh in osmic acid (1 per cent.) for a few hours, and is then macerated for two days or more in water. The epithelium is broken up in dilute glycerine; the cells easily separate from one another on tapping the cover-glass. Notice the two kinds of cells. Sketch some of the cells under a high power.[1]

3. Sections of the external ear (these have been already studied for the cartilage, Lesson XII.).

4. Sections across the cartilaginous part of the Eustachian tube. These may be included in the same preparation that furnishes sections of cochlea. Sketch under the low power.

5. Preparation of the membrana tympani. A piece of the membrane, stained with magenta and gentian violet (see Lesson IX., § 2), is mounted flat in dammar.

Determine the composition of the membrane—*i.e.*, the several layers composing it—by focussing carefully with the high power.

6. Sections across one of the membranous semicircular canals of a fish (skate).

7. Longitudinal sections through the ampulla of a semicircular canal (skate).

6 and 7 may be hardened in chromic and osmic acid (see below under 10) and embedded in celloidin.

8. Golgi preparations of the macula of the utricle from the skate.

9. Teased osmic preparations of the auditory epithelium of an ampulla or of the macula of the utricle, from the skate.

10. Vertical sections through the middle of the cochlea of a mammal (guinea-pig).

The part of the petrosal containing the cochlea is put quite fresh into 0·2 per cent. chromic acid containing one-fifth its volume of 1 per cent. osmic acid, or into undiluted Flemming's solution, or 10 per cent. formol. The decalcification can be effected by the use of the phloroglucin-nitric acid fluid, or by sulphurous acid.[2] When decalcified, the preparation is well washed, and then transferred to alcohols of gradually increasing strength.

The semicircular canals and their ampullæ may also be seen cut across in these sections of the petrosal.

In preparing sections of the membranous labyrinth it is advisable, in order that the epithelium should be kept in position, to embed in celloidin. If the paraffin method of embedding be used, the sections are fixed to the slide by the albumin process. The organ should preferably be stained in bulk.

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[1] The connexion of the olfactory cells with the olfactory nerve-fibres is displayed in embryos, the method of Golgi being employed.

[2] See Appendix.

11. Teased osmic preparations of the epithelium of the organ of Corti from the guinea-pig.

Make sketches from all these preparations under the high power.[1]

THE OLFACTORY MUCOUS MEMBRANE.

The **olfactory region** of the nasal fossæ includes in man the upper and middle turbinate processes and the upper third of the septum. It is covered by a soft vascular mucous membrane of a yellow colour.

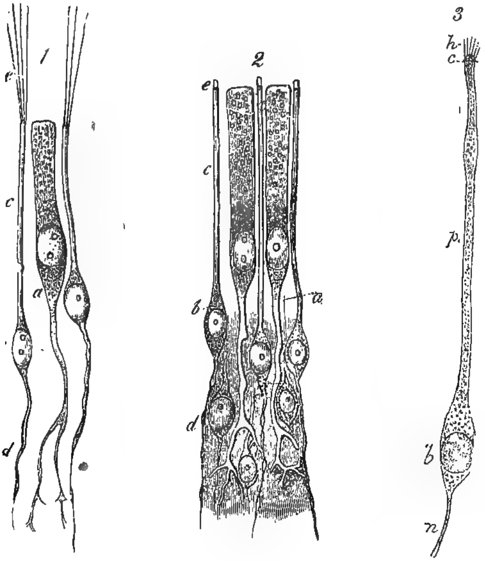

FIG. 696.—CELLS AND TERMINAL NERVE-FIBRES OF THE OLFACTORY REGION. Highly magnified.

1, from the frog; *2* and *3*, from man. In *1* and *2*:—*a*, sustentacular cell, extending deeply into a ramified process; *b*, olfactory cells; *c*, their peripheral rods; *e*, the extremities of these, seen in *1* to be prolonged into fine hairs; *d*, their central filaments. In *3*:—*h*, hairlets; *c*, free border of cell; *p*, peripheral process; *b*, body of cell; *n*, nerve-fibre. *1* and *2* from M. Schultze; *3* from V. Brunn.

The *epithelium* of the olfactory mucous membrane (fig. 696, *2*) is very thick and is composed of long cells, set closely side by side and bounded superficially by a cuticular lamina, through which the free ends of the cells project. The cells are of two kinds: 1. Long, narrow, spindle-shaped, or bipolar nerve-cells consisting of a larger part or body (*b*) containing the nucleus, and of two processes or poles, one (*c*) straight and cylindrical and extending to the free surface, the other (*d*) very delicate and varicose, looking not unlike a nerve-fibril and extending down towards the corium. The position of the nuclear enlargement varies, and with it the relative length of the two processes. The distal or free process terminates in a small clear projection, which passes beyond the cuticular membrane; in amphibia, reptiles, and birds, and perhaps also in mammals, it bears fine stiff hair-like filaments (fig. 696, *1*, *3*). The proximal or varicose process becomes lost amongst the plexus of olfactory nerve-fibres, at the base of the epithelium. It is continuous with one of these fibres, and ultimately passes through the cribriform plate of the ethmoid to end in an arborisation within an olfactory glomerulus (see diagram, fig. 653, p. 492). These cells have been termed the *olfactory cells.* 2. Long columnar epithelium-cells (fig. 696, *a*), with comparatively broad cylindrical nucleated cell-bodies placed next to the free surface, and forked, branching, tail-like processes extending down to the corium. These are regarded not as sensory epithelium-cells, but merely as serving to support the proper olfactory cells. They are termed *sustentacular cells.* 3. Tapering cells are present, at least in some animals, in the deeper part of the epithelium. They rest by their bases upon the corium, and project between the other cells, which they assist to support.

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[1] For details of the somewhat complicated methods of obtaining the various parts of the labyrinth for microscopical examination, the student is referred to the author's *Course of Practical Histology*.

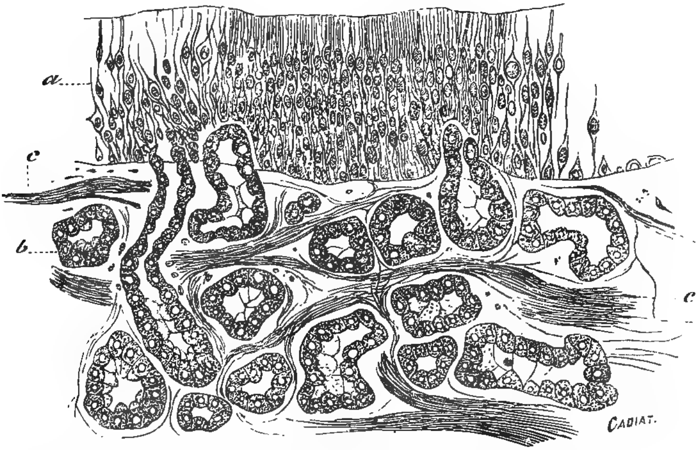

FIG. 697.—SECTION OF OLFACTORY MUCOUS MEMBRANE. (Cadiat.)

a, epithelium; *b*, glands of Bowman; *c*, nerve-bundles.

The *corium* of the olfactory mucous membrane is also thick (fig. 697). It contains, besides numerous blood-vessels, bundles of the olfactory nerve-fibres (which are non-medullated), and a large number of granular-looking serous glands known as *Bowman's glands* (*b*), which open upon the surface by ducts passing between the epithelium-cells.

THE EXTERNAL AND MIDDLE EAR.

The **external ear** proper (*pinna*) is composed of elastic fibro-cartilage, invested by a thin closely adherent skin. The skin is covered by small hairs, and connected with these are the usual sebaceous follicles. In the lobule there is a considerable amount of adipose tissue; voluntary muscular fibres are in places attached to the cartilage of the pinna, and are seen in sections.

The **external auditory meatus** is a canal formed partly of cartilage continuous with that of the pinna, partly of bone. It is lined by a prolongation of the skin and is closed by the membrana tympani, over which the skin is prolonged as a very thin layer. Near the orifice the skin has hairs and sebaceous glands; the meatus is also provided throughout the cartilaginous part with convoluted tubular glands of a brownish-yellow colour, which yield a waxy secretion (*ceruminous glands*). They represent modified sweat glands. A section of one is represented in fig. 698.

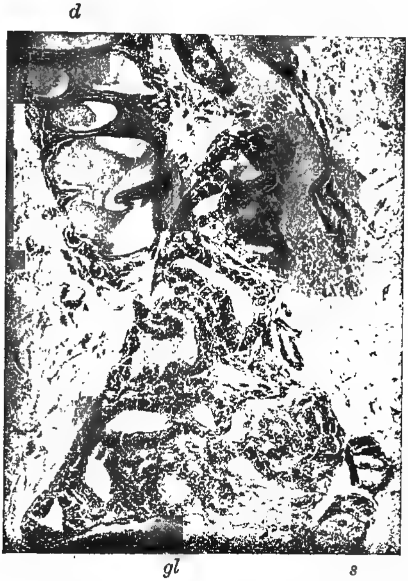

FIG. 698.—SECTION OF CERUMINOUS GLAND OF THE EXTERNAL EAR. Photograph.

d, duct of gland, having a spiral course and therefore cut several times; it is partly filled with cerumen; *gl*, secreting tubules of gland; *s*, extremity of a tubule of a sebaceous gland which extended as far as the base of the ceruminous gland.

The **tympanum** is lined by a mucous membrane which is continuous through the Eustachian tube with the mucous membrane of the pharynx; it is also prolonged into the mastoid cells. The epithelium is columnar and ciliated in some parts, but in others—*e.g.* roof, promontory, ossicles, and membrana tympani—there is a pavement-epithelium.

The **membrana tympani** is a thin membrane formed of fibrous bundles which radiate from a central depression (umbo). Within the radial fibres are a few annular bundles. Covering the fibrous membrane externally is a thin layer continuous with the skin of the meatus; covering it internally is another thin layer, derived from the mucous membrane of the tympanic cavity. A few blood-vessels and lymphatics are distributed to the membrane, chiefly in the cutaneous and mucous layers.

The **Eustachian tube** is the canal leading from the tympanum to the pharynx. It is formed of bone near the tympanum, but below, near the pharynx, it is bounded partly by a bent piece of cartilage (fig. 699, 1, 2), partly by fibrous tissue. The latter contains numerous mucous glands (6, 7), which open into the tube, and on the outer side a band of muscular tissue (3) which joins the tensor palati. The epithelium is ciliated.

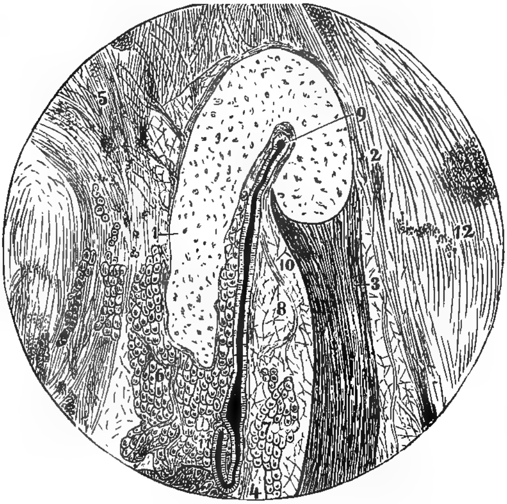

FIG. 699.—SECTION ACROSS THE CARTILAGINOUS PART OF THE EUSTACHIAN TUBE. (Rüdinger.)

1, 2, bent cartilaginous plate; 3, musc. dilatator tubæ; to the left of 4, part of the attachment of the levator palati muscle; 5, fibrous tissue uniting the tube to the base of the skull; 6 and 7, mucous glands; 8, 10, fat; 9 to 11, lumen of the tube; 12, connective tissue on the lateral aspect of the tube.

THE INTERNAL EAR.

The *labyrinth*, which is the essential part of the auditory organ, consists of a complex membranous tube lined by epithelium and filled with endolymph, contained within a bony tube—the osseous labyrinth—of corresponding complexity of shape (figs. 700, 701). The membranous labyrinth does not wholly fill the bony cavity; the rest of the space is occupied by perilymph.

The membranous labyrinth (fig. 700) is composed of the *utricle* (*u*), the three *semicircular canals* (each with an enlargement or *ampulla* at one end), the *saccule* (*s*), and the *canal of the cochlea* (*c.c.*).

The branches of the auditory nerve pass to certain parts only of the membranous labyrinth, viz., the maculæ of the utricle and saccule, the cristæ of the ampullæ, and along the whole length of the canal of the cochlea (the shaded parts in fig. 700). At these places the lining epithelium is specially modified to form a sensory or nerve-epithelium; elsewhere it is a simple pavement-epithelium.

The **membranous semicircular canals** and the **utricle** and **saccule** are composed of fibrous tissue, which is adherent along one side to the endosteum of the bony canal; from the opposite side bands of fibrous tissue pass across the perilymph (fig. 702). Within the fibrous membrane is a thick clear tunica propria, which, in the semicircular canals, may form papilliform elevations in the interior of the tube.

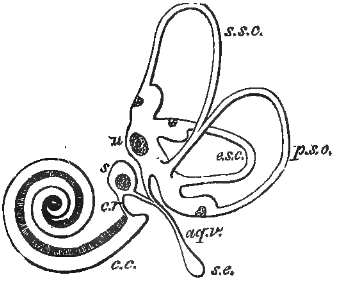

FIG. 700.

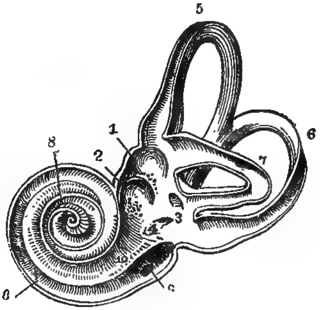

FIG. 701.

FIG. 700.—PLAN OF THE RIGHT MEMBRANOUS LABYRINTH VIEWED FROM THE MESIAL ASPECT. Magnified 2½ times.

u, utricle, with its macula; *s.s.c.*, *p.s.c.*, and *e.s.c.*, the three semicircular canals with their ampullæ; *s*, saccule; *aq.v.*, aquæductus vestibuli; *s.e.*, saccus endolymphaticus; *c.r.*, canalis reuniens; *c.c.*, canal of the cochlea.

FIG. 701.—VIEW OF THE INTERIOR OF THE LEFT OSSEOUS LABYRINTH.

The bony wall of the labyrinth is removed superiorly and externally. 1, fovea hemielliptica; 2, fovea hemisphærica; 3, common opening of the superior and posterior semicircular canals; 4, opening of the aqueduct of the vestibule; 5, the superior; 6, the posterior, and 7, the external semicircular canals; 8, spiral tube of the cochlea; 9, scala tympani; 10, scala vestibuli.

The places of entrance of the nerve-fibres are marked in each ampulla by a transverse, inwardly projecting ridge (*crista*), in the saccule and utricle by a broader thickening of the tunica propria (*macula*). The epithelium at these places is formed of columnar cells (fig. 703), which are surmounted by long, stiff, tapering hairs (fig. 703, *h*; fig. 704). Around these *hair-cells* the axis-cylinders of the nerve-fibres ramify (fig. 705); they are therefore—like the gustatory cells of the taste-buds—sensory epithelium-cells. Between them are a number of thin and somewhat rigid nucleated cells (*fibre-cells of* Retzius), which rest upon the basement-membrane, and are connected at their free extremity with a cuticular membrane, through which the above-mentioned hairs project.

The hairs do not jut freely into the endolymph, but into a soft mucus-like substance, of a dome-like form in the ampullæ (*cupula terminalis*, fig. 703); in the saccule and utricle this substance has a quantity of calcareous particles (*otoliths*) embedded in it.

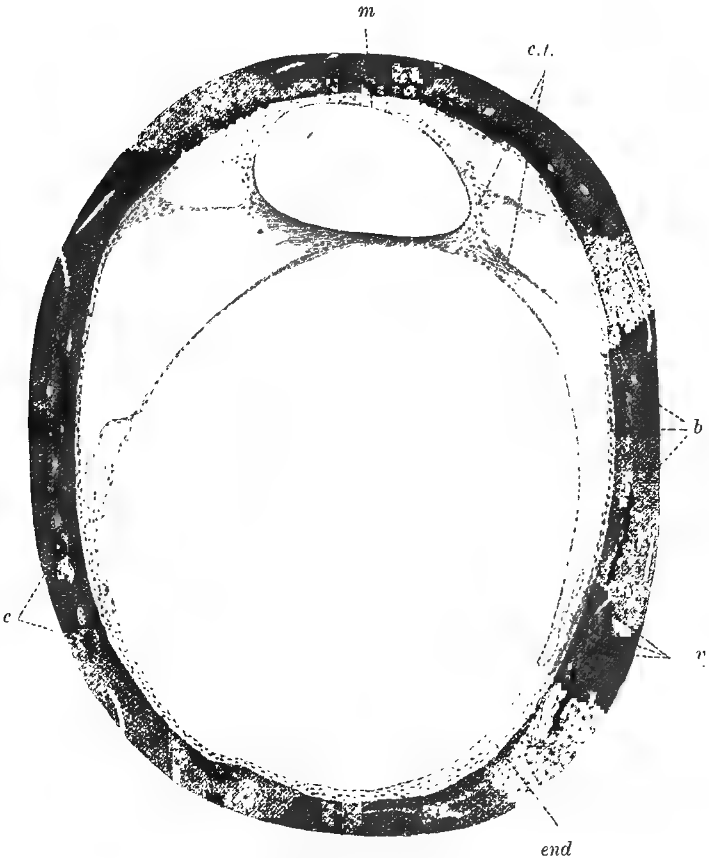

FIG. 702.—SECTION OF SEMICIRCULAR CANAL, NEW-BORN CHILD. (Sobotta.) Magnified 55 diameters.

c.t., connective-tissue strands, between membranous canal and endosteum of bony canal; *m*, membranous canal; *b*, wall of bony canal; *c*, remains of fœtal cartilage; *end*, endosteum; *v*, blood-vessels.

The **cochlea** consists of a bony tube coiled spirally around an axis which is known as the *columella* (figs. 706, 707). The tube is divided along its length by a partition—formed partly by a projecting lamina of bone (*spiral lamina*), partly by a flat membrane (*basilar membrane*)—into two parts (*scalæ*); the upper (supposing the cochlea resting base downwards) being termed the *scala vestibuli*, the lower *scala tympani*; the latter is closed near its larger end by the membrane of the fenestra rotunda through which, in the macerated bone, the cavity of the tympanum communicates with the scala tympani. The scalæ are lined by endosteum, and are filled with perilymph, continuous with that of the rest of the labyrinth at the commencement of the scala vestibuli; they communicate with one another at the apex of the cochlea by an opening, the *helicotrema*.

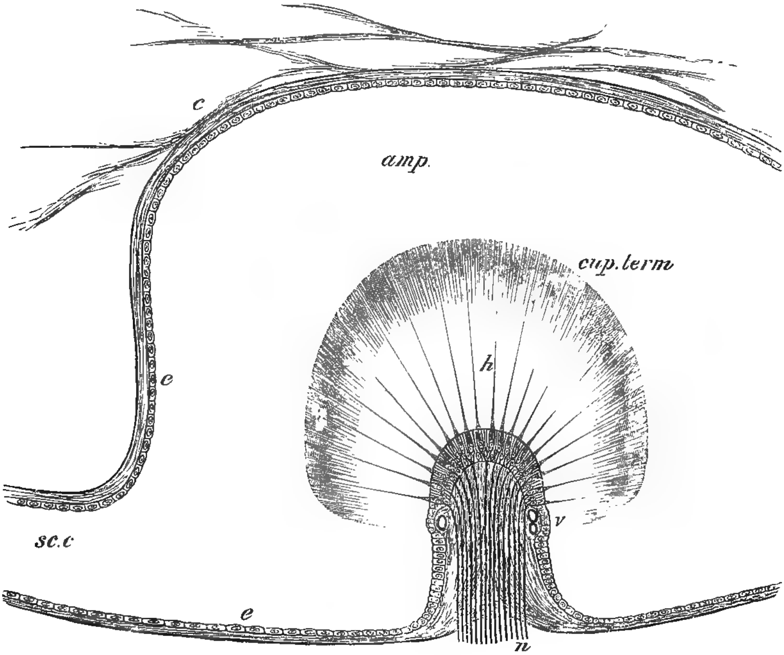

FIG. 703.—LONGITUDINAL SECTION OF AN AMPULLA OF A FISH THROUGH THE CRISTA ACUSTICA (DIAGRAMMATIC).

amp., cavity of the ampulla; *sc.c.*, semicircular canal opening out of it; *c*, connective tissue attached to the wall of the membranous ampulla and traversing the perilymph; *e*, *e*, flattened epithelium of ampulla; *h*, hairs projecting from the columnar cells of the epithelium into the cupula, *cup.term.*; *v*, blood-vessels; *n*, nerve-fibres entering the base of the crista and passing into the columnar epithelium.

The scala vestibuli does not occupy the whole of that part of the bony tube of the cochlea which is above the partition just mentioned. Its outer and lower third is cut off by a delicate connective-tissue membrane (*membrane of Reissner*, fig. 708, *R*), which springs from near the end of the spiral lamina, and passes upwards and outwards to the outer wall, thus separating a canal (*d.c.*) triangular in section, which is lined by epithelium, and represents the membranous labyrinth of the cochlea (*duct or canal of the cochlea*).

The floor of the canal of the cochlea is formed (1) of the extremity of the spiral lamina, which is thickened above by a peculiar kind of connective tissue, forming an overhanging projection known as the *limbus*

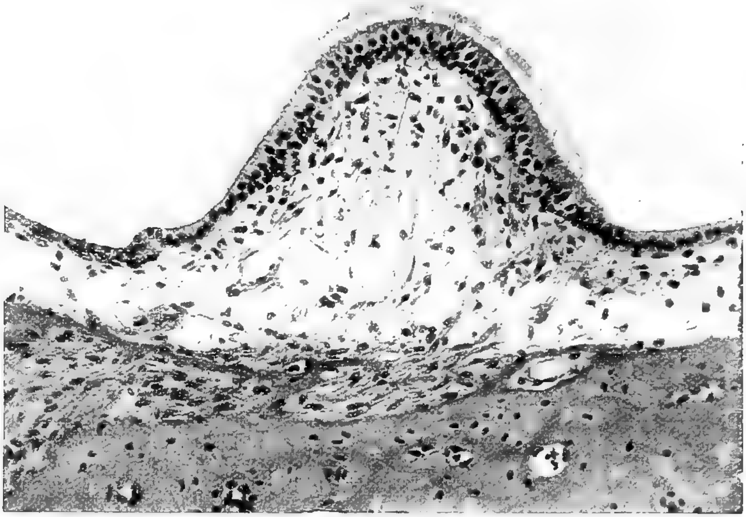

FIG. 704.—SECTION OF AMPULLA OF GUINEA-PIG. Photographed from a preparation by H. Pringle.

e, epithelium becoming columnar over the crista, where the cells are furnished with hairlets; *c*, corium of delicate connective tissue, with the nerve-fibres passing to the epithelium; *b*, bone, with canals containing bundles of nerve-fibres.

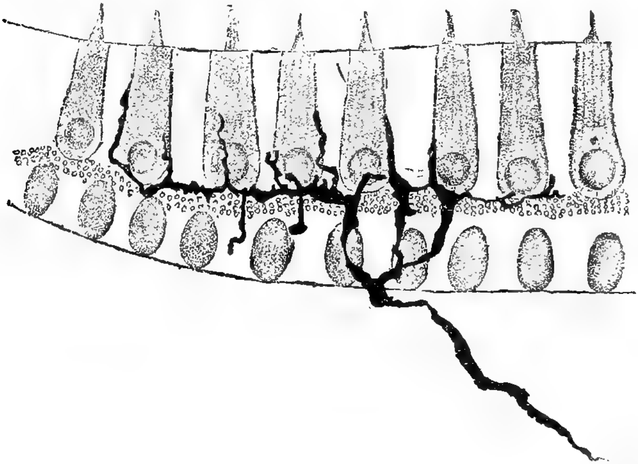

FIG. 705.—NERVE TERMINATIONS IN MACULA: GOLGI METHOD. (v. Lenhossék.)

(fig. 708, *l*); and (2) of the basilar membrane (*b.m.*), which stretches across from the end of the bony lamina to the outer wall, and is attached to this by a projection of reticular connective tissue termed the *spiral ligament* (*l.sp*).

The *basilar membrane* is composed of stiff straight fibres, which extend from within out, and are embedded in a homogeneous substance. The membrane is covered below by a layer of connective tissue continuous with the endosteum of the scala tympani; the modified epithelium which forms the *organ of Corti* rests upon its upper surface. It becomes gradually broader in the upper turns of the cochlea (rather more than twice as broad in the uppermost as compared with the lowermost turn), and its constituent fibres become therefore gradually longer.

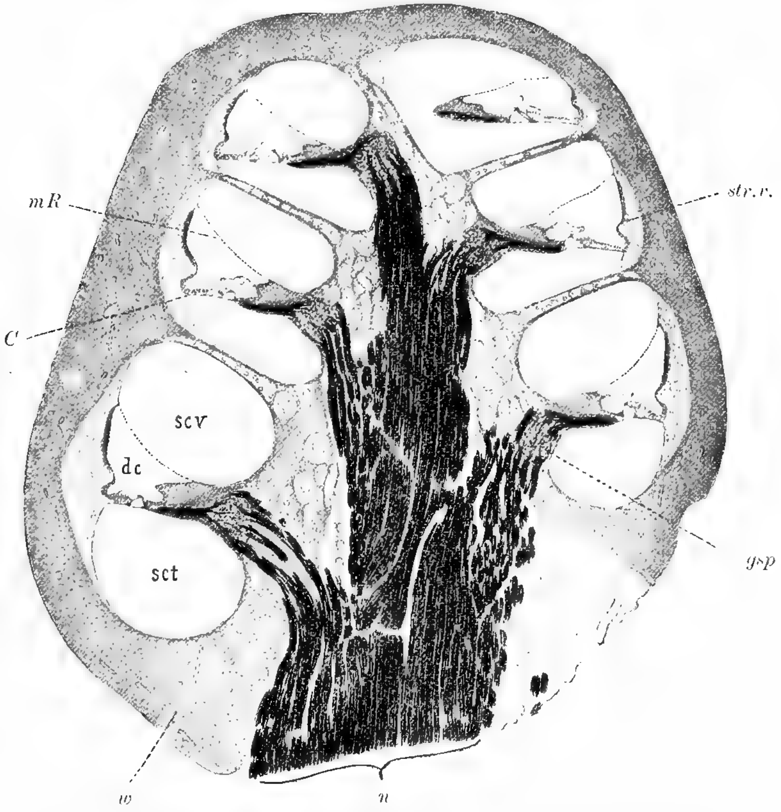

Fig. 706.—Section through the cochlea of the cat. (Sobotta.) Magnified 25 diameters.

dc, duct of cochlea; *scv*, scala vestibuli; *sct*, scala tympani; *w*, bony wall of cochlea; *C*, organ of Corti on membrana basilaris; *mR*, membrane of Reissner; *n*, nerve-fibres of cochlear nerve; *gsp*, ganglion spirale; *str.v.*, stria vascularis.

The **organ of Corti** consists of the following structures:—

1. The *rods of Corti*, two series (inner and outer) of stiff, striated structures, of a peculiar shape, the inner somewhat like a human ulna, the

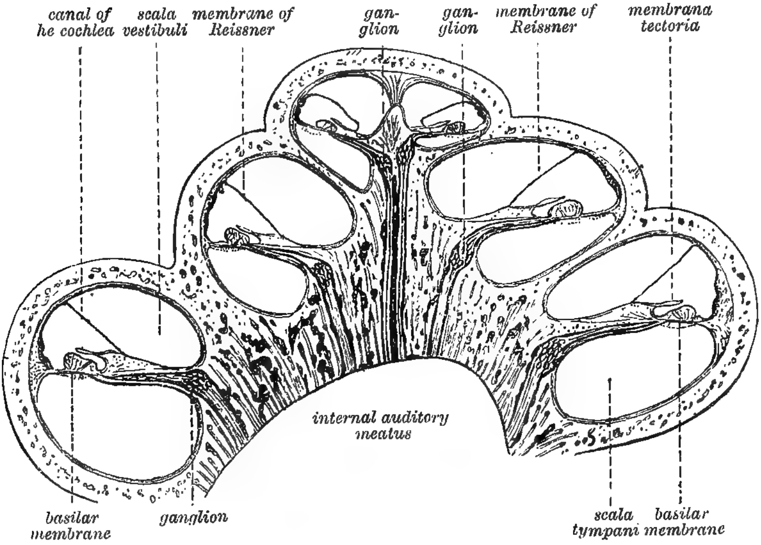

FIG. 707.—VERTICAL SECTION THROUGH THE MIDDLE OF THE HUMAN COCHLEA. (Diagrammatic.)

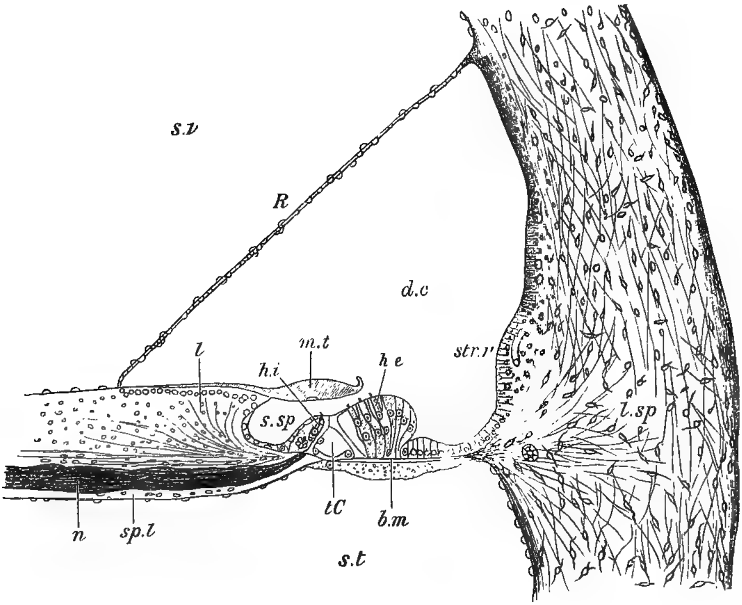

FIG. 708.—VERTICAL SECTION OF THE FIRST TURN OF THE HUMAN COCHLEA. (G. Retzius.)

s.v, scala vestibuli; *s.t*, scala tympani; *d.c*, canal or duct of the cochlea; *sp.l*, spiral lamina; *n*, nerve-fibres; *l.sp*, spiral ligament; *str.v*, stria vascularis; *s.sp*, spiral sulcus; ***R***, section of Reissner's membrane; *l*, limbus laminæ spiralis; *m.t*, membrana tectoria; *tC*, tunnel of Corti; *b.m*, basilar membrane; *h.i*, *h.e*, internal and external hair-cells.

outer like a swan's head and neck (fig. 709). They rest by one extremity (the foot) on the basilar membrane a short distance apart, and are inclined towards one another, their larger ends (heads) being jointed together; the series of rods thus enclose a sort of tunnel, the floor of which is formed by a part of the basilar membrane (fig. 711). Close to their feet may usually be seen the remains of the cells from which they have been formed. The inner rods are narrower and rather more numerous than the outer. The head of each outer rod has a process which extends outwards and is known as the phalangeal process. This forms part of—

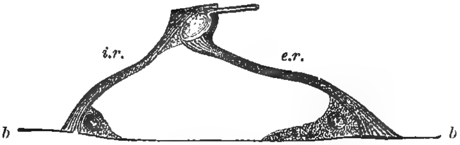

Fig. 709.—A pair of rods of Corti, from the rabbit's cochlea, in side view. Highly magnified.

b, *b*, basilar membrane; *i.r.*, inner rod; *e.r.*, outer rod. The nucleated protoplasmic masses at the feet, which represent the cells from which the rods have been formed, are also shown.

2. A *reticular lamina* (fig. 711, *l.r.*), which is a cuticular structure extending like a wire-net over the outer epithelium-cells of the organ of Corti, and is composed of two or three series of stiff fiddle-shaped rings (*phalanges*) cemented together in such a manner as to leave square or oblong apertures through which the hairlets of the outer hair-cells project.

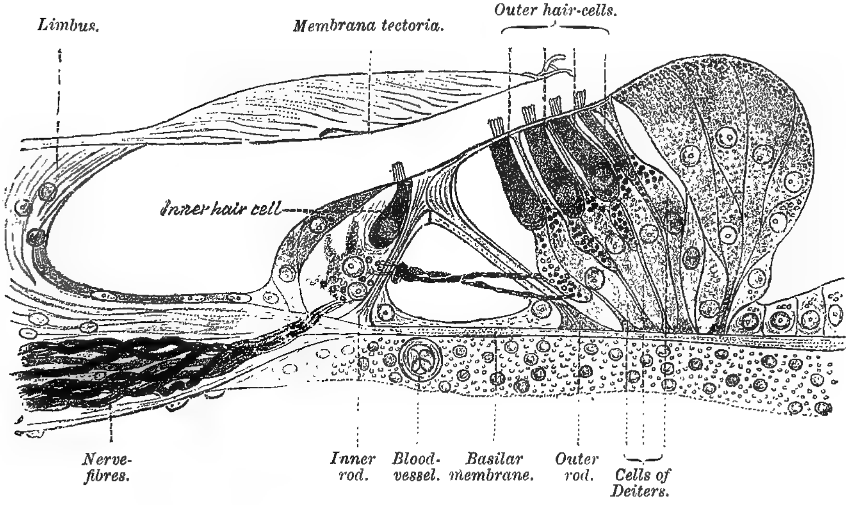

Fig. 710.—Section through the organ of Corti of the human cochlea. (G. Retzius.) Highly magnified.

3. The *outer hair-cells* placed external to the rods of Corti. These are

epithelium-cells of columnar shape, arranged in three series (four in man, fig. 710). The free extremity of the cell is surmounted by a bundle of short *auditory hairlets*, and projects through one of the apertures in the reticular lamina; the fixed extremity is prolonged into a stiff cuticular process, which is attached to the basilar membrane. Between the hair-cells are other (sustentacular) cells which are tapered in the same manner, but rest by their larger end upon the basilar membrane, and are prolonged above into a cuticular process which is attached to the reticular lamina (*cells of Deiters*, figs. 710, 712).

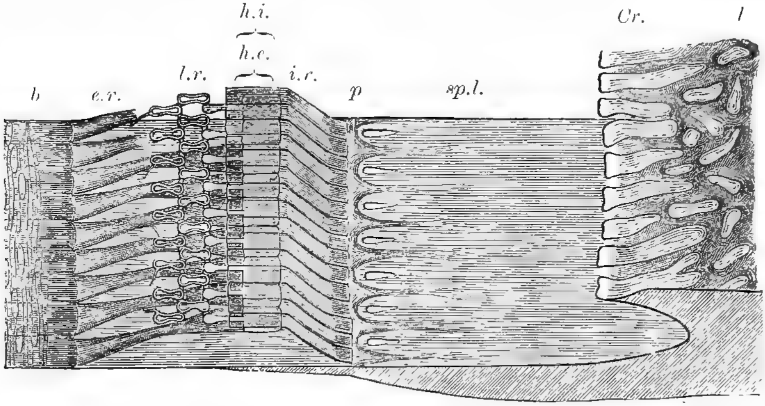

FIG. 711.—SEMI-DIAGRAMMATIC VIEW OF PART OF THE BASILAR MEMBRANE AND TUNNEL OF CORTI OF THE RABBIT, FROM ABOVE AND THE SIDE. Much magnified.

l, limbus; *Cr.*, extremity or crest of limbus with tooth-like projections; *b*, basilar membrane; *sp.l.*, spiral lamina with, *p*, perforations for transmission of nerve fibres; *i.r.*, fifteen of the inner rods of Corti; *h.i.*, their flattened heads seen from above; *e.r.*, nine outer rods of Corti; *h.e.*, their heads, with the phalangeal processes extending outward from them and forming, with the two rows of phalanges, the lamina reticularis, *l.r.*

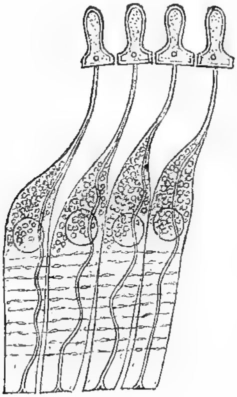

FIG. 712.—FOUR CELLS OF DEITERS FROM THE RABBIT. (G. Retzius.) Highly magnified.

The varicose lines are nerve-fibrils. The phalangeal processes are attached above to a portion of the lamina reticularis.

4. The *inner hair-cells* (fig. 710), placed internal to the rods of Corti,

They form a single series of columnar cells surmounted by auditory hairlets, lying in close apposition to the inner rods.

The remaining epithelium-cells have no important characteristics. They are long and columnar next to the outer hair-cells, but soon diminish in size and become cubical; in this form they are continued over the outer wall of the cochlear canal. Here they cover a very vascular membrane (*stria vascularis*, fig. 708, *str.v.*), which is frequently pigmented; its capillary blood-vessels penetrate between the epithelium-cells. Internal to the inner hair-cells the epithelium also soon becomes cubical; it is prolonged over the

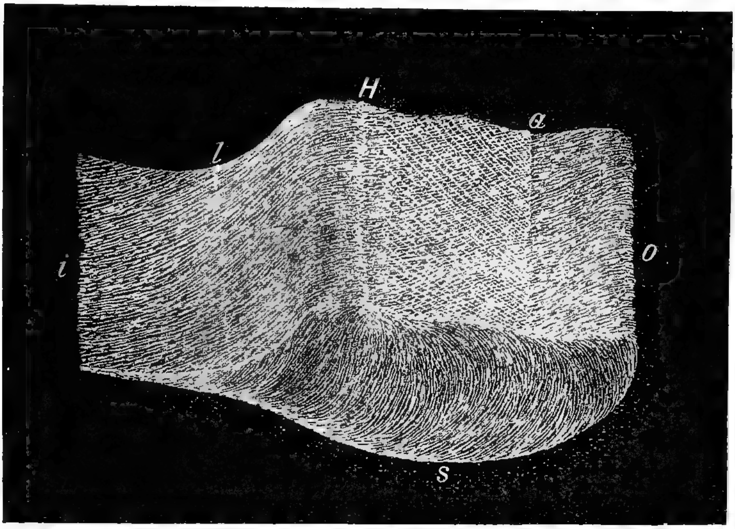

FIG. 713.—PORTION OF MEMBRANA TECTORIA OF PIG, DISPLAYING THE UNDER SURFACE AND A CROSS SECTION. (Hardesty.)

i, thinner edge by which it is attached to the limbus; *o*, distal edge; *s*, section showing arrangement of crossed fibres; *l*, line impressed by edge of limbus; *H*, line of Hensen, which overlies the heads of the rods of Corti; ***H*** to *a*, latticed layer on under surface.

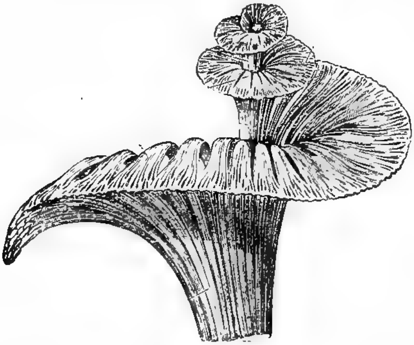

FIG. 714.—GENERAL VIEW OF THE MODE OF DISTRIBUTION OF THE COCHLEAR NERVE, ALL THE OTHER PARTS HAVING BEEN REMOVED. (Arnold.)

limbus of the spiral lamina. The epithelium of Reissner's membrane is of the pavement variety.

The *membrana tectoria* (figs. 708, 710, 713) is a soft, fibrillated structure, which is attached along the upper surface of the limbus where it is thin: it lies like a pad over the organ of Corti. It has a thin distal prolongation which is reticular in appearance when seen on the flat. According to Retzius this thin part is attached to the lamina reticularis. Probably the lower surface of the membrane rests on the epithelium of the organ of Corti during life, although in sections it usually appears raised a short distance above the auditory hairs.

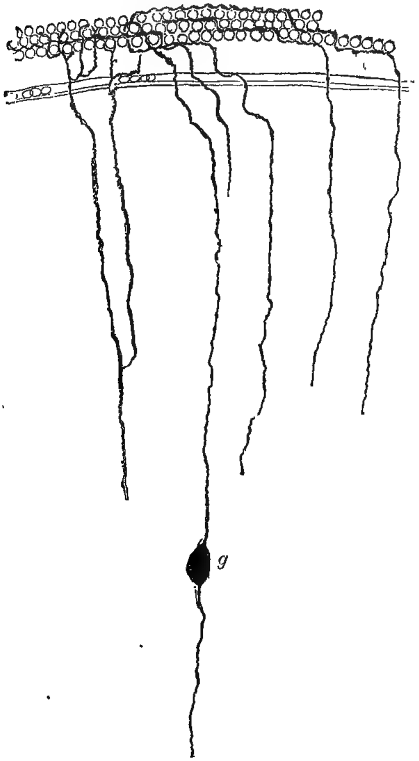

FIG. 715.—ENDING OF SOME OF THE FIBRES OF THE COCHLEAR NERVE AMONGST THE HAIR-CELLS. (G. Retzius.)

This preparation is made by Golgi's method, and is viewed from above. *g*, a cell belonging to the spiral ganglion.

The fibres of the cochlear branch of the auditory nerve enter the base of the columella, and run in canals through its substance (figs. 706, 707), being gradually deflected outwards, as they pass through it, into the spiral lamina; at the base of this they swell out into a continuous ganglionic cord (*spiral ganglion*). The fibres take origin from the cells of this ganglion.

After leaving the ganglion and traversing the spiral lamina they emerge in bundles, and, having lost their medullary sheath, they then pass into the epithelium of the inner hair-cell region. Here some of them turn at a right angle and are directly applied to the inner hair-cells, whilst others cross the tunnel of Corti, to become applied in like manner to the outer hair-cells and the cells of Deiters (figs. 710, 715). The nerve-fibrils apparently lie between and in close contact with these cells, but there does not appear to be any direct continuity between the fibrils and the cell-substance.

APPENDIX.

METHODS USED IN HISTOLOGY.[1]

Mounting solutions :—1. *Normal salt solution.*—A 0·6 to 0·9 per cent. solution of common salt is used in place of serum for mounting fresh tissues for immediate examination. The lower percentage is used for frog's tissues, the higher for mammals. *Ringer's solution* may be substituted for normal salt solution with advantage. The composition of Ringer's solution for mammalian tissues is as follows:—NaCl, ·9 gm.; KCl, ·042 gm.; $CaCl_2$, ·024 gm.; in 100 c.c. distilled water. For frog tissues ·6 gm. NaCl is taken. Preparations mounted in these salt solutions cannot be preserved permanently.

2. *Glycerine*, diluted with an equal quantity of water. The cover-glass should be fixed by gold size.

3. *Farrant's solution.*—This is made by dissolving 10 gm. of clear picked gum arabic in 10 c.c. distilled water, and mixing with 5 gm. glycerine. A piece of camphor is added to prevent the growth of moulds. As a mounting medium Farrant's solution has the advantage over glycerine of setting firm at the edges of the cover-glass.

4. *Canada balsam*, from which the volatile oils have been driven off by heat, dissolved in xylol.

5. *Dammar solution*, made by dissolving dammar resin in xylol. The solution is filtered through paper wetted with chloroform. This is used for the same purpose as xylol balsam and has the advantage of remaining colourless, whereas Canada balsam becomes yellow with keeping.

6. *Acetate of potassium*, a nearly saturated solution. This is the best medium for osmic preparations and is also used for iodine-stained preparations, to show glycogen within cells. The cover-glass is fixed by soluble glass or by gold size.

General methods of preserving and hardening tissues and organs.—The following fluids are used: Alcohol (75 per cent. to absolute); acetone; Carnoy's fluid (absolute alcohol 60 c.c., chloroform 30 c.c., glacial acetic acid 10 c.c.); formol (diluted with from 9 to 99 parts of water); corrosive sublimate (saturated solution in normal salt solution); chromic acid solution (1 in 200 to 1 in 500, to which glacial acetic acid may advantageously be added in the proportion of 2 parts acetic acid to 1000 chromic solution); picric acid solution (saturated) either alone or containing 2 parts of nitric or sulphuric acid to 1000, or mixed with an equal volume of 10 per cent. formol; Mann's fluid (a mixture of equal parts of saturated aqueous solutions of mercuric chloride and picric acid; to this mixture formol may be added to the extent of 5 per cent.); osmic acid solution (1 to 2 per cent.); bichromate of potassium solution (3 per cent.), to which glacial acetic acid may advantageously be added to the extent of 5 per cent. (Tellyesniczky), or formol to the extent of 10 per cent. (the latter especially for the central nervous system); Müller's fluid (bichromate of potassium 2½ parts, sulphate of soda 1 part, water 100 parts); Zenker's fluid (this is Müller's fluid containing 5 parts per cent. of mercuric chloride, to which 5 c.c. of acetic acid is added at the time of using: Kingsbury recommends the addition of 10 parts formol and 4 parts copper sulphate); and solutions of bichromate of potassium and osmic acid in varying proportions. Thus Altmann's fluid (for displaying cell-granules) consists of a mixture of equal parts of 2·5 per cent. bichromate of potassium solution and 2 per cent. osmic acid.

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[1] For fuller details than can be here given of the methods used in Histology, the reader is referred to the *Enzyklopædie der mikr. Technik*, 1908, edited by R. Krause. An excellent account of the methods and theory of fixation and staining is contained in Mann's *Physiological Histology*, Oxford, 1902.

It is best, if possible, to inject the fixing fluid into the blood-vessels after washing them out with warm Ringer; if this is not possible, very small pieces of tissue should be taken, and always a considerable amount of the fixing fluid.

The solution of most general application is formol. This is a 40 per cent. solution of formaldehyde. It should be made up with normal saline instead of water (Mann) in the proportion of 10 parts formol to 90 saline; it penetrates readily and hardens quickly. The tissue should not be left in the formol more than a few days, but transferred to alcohol. For rapid fixation a very small piece of the tissue is placed in 10 per cent. formol and warmed to a temperature of about 40° or 50°; it will be sufficiently fixed in half an hour for sections to be made by the freezing method. Or the piece may be transferred from the formol solution first to weak and then to increasing strengths of alcohol, and finally to xylol, so that it is ready for embedding in paraffin in an hour.

Pure acetone is also of utility for rapid fixation and hardening. Small pieces of the tissue are dropped into a large amount of acetone, which not only fixes and hardens but also dehydrates, so that the tissue can be transferred in an hour or so direct to molten paraffin for embedding. But better results are got by placing in warm 10 per cent. formol for thirty minutes, and then transferring to acetone. Acetone is also useful for dehydrating methylene blue stained preparations instead of alcohol.

For preserving the structure of cells and nuclei, one of the best fixing fluids is that recommended by Flemming. This consists of 15 vols. of 1 per cent. chromic acid, 4 vols. of 2 per cent. osmic acid, and 1 vol. glacial acetic acid. It must be quite freshly prepared. It is sometimes diluted with from two to five times its bulk of water before use. One day is sufficient for fixation and hardening; the pieces of tissue must be very small. The tissue should be washed for several hours in running water after removal from the mixture, and then placed in 80 per cent. alcohol. Tissues fixed in any mixture containing osmic acid stain with difficulty. The best stains for use in this case are saffranin, gentian violet, acid fuchsin or carmalum. Carnoy's fluid (see previous page) is in many cases excellent for cell-structure and division, and very rapid in its action. For soft and delicate objects it is probably the best fixing reagent. It can be used with advantage for the fœtal brain which shrinks in most fixatives. After three hours or more in Carnoy's fluid the preparation is transferred to absolute alcohol, and after twenty-four hours in this it is ready for embedding. Zenker's fluid is also of great value for exhibiting the finer structure of cells.

Tissues to be hardened in alcohol may be placed at once in absolute alcohol, but for some tissues it is best to begin with 50 per cent. alcohol, and pass the pieces through successive grades of 75 per cent., and 95 per cent., into absolute alcohol, leaving them a few hours in each. They are ready for embedding as soon as they are dehydrated, but as a rule they may be left a long time in alcohol without deteriorating. Organs which contain much fibrous tissue, such as the skin and tendons, should not go into stronger alcohol than about 80 per cent.; otherwise they become too hard to cut. Alcohol (80 to 90 per cent.) is generally used after other fixing reagents, partly to complete the hardening, partly on account of its dehydrating property, but previous to embedding in paraffin all trace of water must be removed by absolute alcohol. If mercuric chloride be used for hardening, iodine may be added to the alcohols subsequently used (except the final alcohol), to get rid of a mercurial precipitate which forms in the tissue. This object can, however, be effected by washing the sections with a solution of iodine in alcohol. A mixture of mercuric chloride (saturated solution) (2 parts) and alcohol (1 part) is sometimes used; it requires about two days to harden a tissue. Mercuric chloride is one of the best fixatives for obtaining the full value of dyes, but it is slow in penetration and difficult to wash out the excess of the salt. The pieces taken must always be very small, and must be washed at least twenty-four hours in running water and then kept in a large quantity of 80 per cent. alcohol. The washing with running water is useful after most fixatives.

Many tissues are instantly fixed by being plunged for a minute into boiling water and then placed in alcohol; this is not, however, a good method for glands.

For tissues that are to be hardened in chromic acid an immersion of from seven to fourteen days is generally necessary; they may then, after washing for some hours or days in running water, be placed in alcohol for preservation and to complete the process of hardening. The alcohol should be changed once or twice.

Organs placed in bichromate of potassium or Müller's fluid are ready for section in a fortnight or three weeks; they may, however, be left a longer time in those fluids without deterioration.

With picric acid the hardening process is generally complete in two days; the organs may then be transferred to alcohol, which must be frequently changed.

The hardening of the brain and spinal cord in Müller's fluid takes from three weeks to as many months. It is hastened by warmth, and by the addition of acetic acid to the fluid.

Tissues containing calcareous matter, *e.g.* bone and tooth, may be rapidly decalcified in a solution made by dissolving, with the aid of heat, 1 gm. phloroglucin in 10 c.c. nitric acid, and filling up to 100 c.c. with water, to which more nitric acid may be added if desired. Another rapid decalcifying fluid is commercial sulphurous acid solution. If it is desired to preserve the soft parts within the bone, it should first be placed for a few hours in 10 per cent. formol. For decalcifying more slowly, a 1 to 5 per cent. solution of nitric acid in water or alcohol, a saturated solution of picric acid containing a superabundance of crystals, or a 1 per cent. solution of chromic acid may be employed. After decalcification the tissue must always be washed in running water for at least twenty-four hours.

Embedding of hardened tissues, and preparation of sections.—Sections are most advantageously made with some form of microtome. It is generally needful to support the hardened tissue whilst it is being cut; with this object it is embedded in some substance which is applied to it in the fluid condition and becomes solid on standing. The embedding substance can either simply enclose the tissue, or the tissue may be soaked in it; the latter method is the one commonly employed.

The embedding substance chiefly used is paraffin of about 50° C. melting point. The precise temperature depends upon that of the atmosphere. In summer and in hot climates a paraffin of higher melting point may be required.

Embedding in paraffin.—Before being soaked in melted paraffin, the piece of tissue may be stained in bulk (see p. 545); it is then dehydrated by a series of alcohols (50 per cent., 75 per cent., 95 per cent.), finishing up with absolute alcohol; after which it is soaked in cedar-wood oil, xylol, or chloroform. If chloroform is employed the piece of tissue can be left overnight in a saturated solution of paraffin in chloroform. This is especially advantageous for delicate objects. The prepared piece is now transferred to molten paraffin, which should not be too hot but kept only just molten: it is soaked in this for from one to several hours, according to thickness. When thoroughly impregnated with the paraffin the object is placed in a paper mould or a glass which has been smeared with glycerine, and partly filled with the molten paraffin: more of this is then poured in, and the whole allowed to cool quickly. A square block of the paraffin containing the tissue is then cut out and fixed in the desired position on the microtome, thin sections are made and fixed to a slide (see below), the paraffin dissolved out by xylol, and the sections mounted in dammar.

If it be desired to cut a riband of successive sections, and the paraffin used prove too hard for them to stick to one another at the edges, a paraffin of lower melting point (40° C.) is smeared over the opposite sides of the block; the sections then adhere together as they are cut.

Preparation of frozen sections.—The bichromate solutions and formol are the best fluids to use for preserving tissues which are to be frozen in place of being embedded. If alcohol is employed for fixation it should be thoroughly washed out with water. The tissue is soaked in gum-water before being placed upon the freezing microtome. A thin syrup of either gum arabic or dextrin may be used. The preliminary soaking in gum is not necessary after formol.

Embedding in celloidin.—The piece to be embedded, which should not be thicker than 2 or 3 mm., is dehydrated by absolute alcohol, transferred for a few hours to a mixture of equal parts of absolute alcohol and ether, and then placed another twenty-four hours or more in a solution of celloidin in alcohol and ether similar in strength to ordinary collodion; finally it goes into collodion of double strength. After twenty-four hours in this it is removed and placed upon a wood or metal or vulcanite holder. When the celloidin is set by evaporation of its ether the holder is plunged in alcohol (80 to 85 per cent.); after a few hours, sections may be cut with a knife wetted with spirit of the same strength. The sections are placed in 95 per cent. alcohol; then passed through cedar-wood oil or bergamot oil into dammar. They must not go into clove oil, nor into absolute alcohol. The advantage of the method is that the celloidin, which is quite transparent, need not be got rid of in mounting the sections, and serves to keep the parts of a section together; it is thus very useful for friable tissues or for large sections. The tissue may either be stained in bulk before embedding, or the sections may be stained. They can be attached to the slide, by transferring them to it from 95 per cent. alcohol, and then allowing ether vapour to pour out of a half full bottle on to their surface. They may then be pressed down by covering with filter or tissue paper, the thumb being then passed firmly over the paper; this fixes them securely enough to allow of their being treated by staining and clearing solutions.

Microtomes.—A section-cutting apparatus or microtome is essential for histological work. Useful instruments for students are the Cathcart microtome for freezing and the tripod microtome for objects which have been embedded in paraffin.

The tripod microtome is a simple and efficient little instrument, and has the advantage of being inexpensive. It consists of a metal frame (fig. 716) in which a razor is fixed, provided with a micrometer screw by which the height of the razor-edge is adjusted. The paraffin block containing the tissue is fixed by the aid of heat on a flat piece of glass over which the tripod slides. The razor-edge is lowered after each successive section.

In the Cathcart freezing microtome (fig. 717) the tissue, after being soaked in gum-water, is placed on a metal plate and frozen by playing an ether or other refrigerating spray on the under surface of the plate. The plate is moved upwards

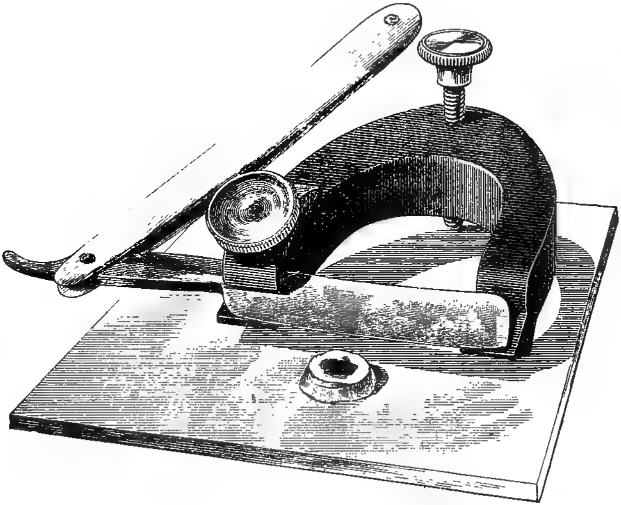

FIG. 716.—TRIPOD MICROTOME. (Birch's pattern.)

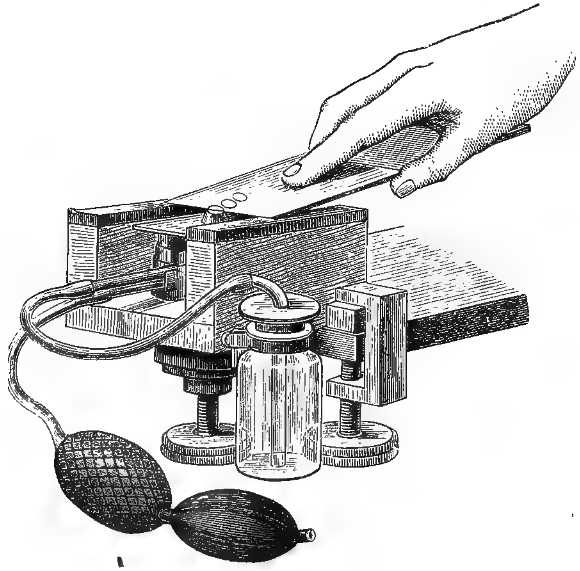

FIG. 717.—CATHCART FREEZING MICROTOME.

by a finely-cut screw, and the knife or plane used to cut the sections is guided over the plate by passing over glass slips. In the original Williams' microtome the freezing agent was ice and salt mixture. When using any freezing microtome, especially for the nervous system, it is important not to cut when the tissue is frozen too hard, or the sections will roll up and break.

Somewhat more expensive and complicated, but also more efficient, instruments are the rocking microtome of the Cambridge Scientific Instrument Company (fig. 718) and the microtomes designed by C. S. Minot and by Delépine: the last is arranged for freezing with liquid CO_2. The action of all of these is automatic. For

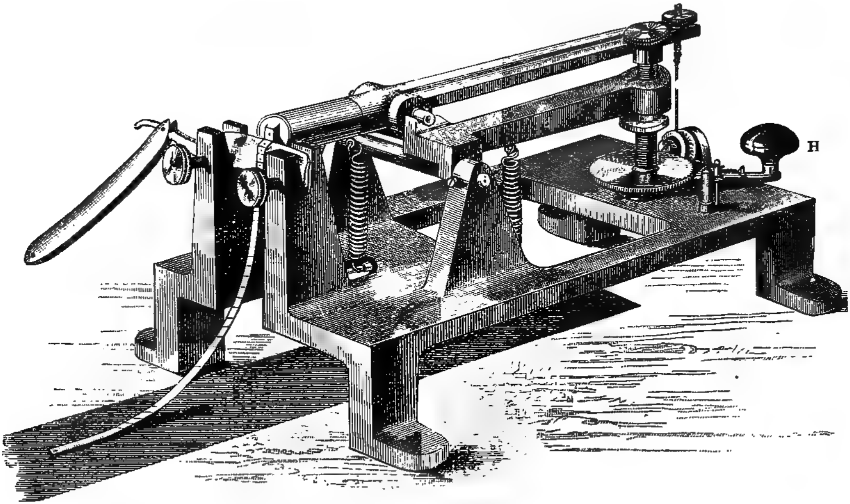

FIG. 718.—ROCKING MICROTOME.

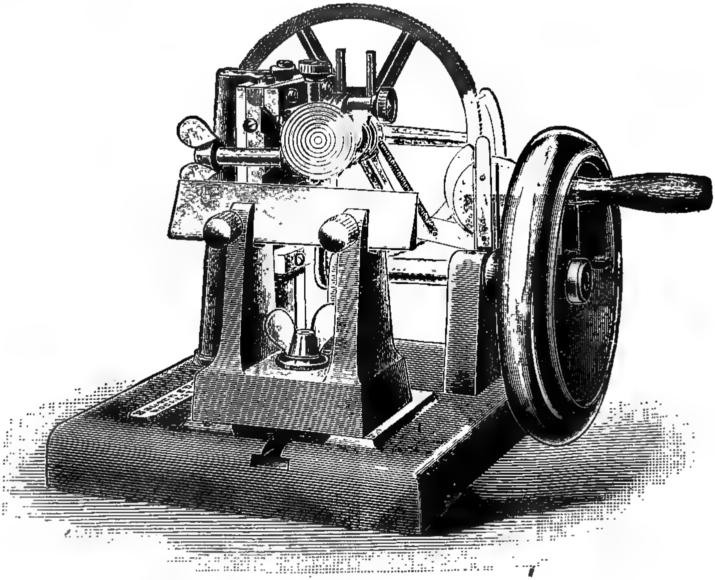

FIG. 719.—MINOT'S AUTOMATIC ROTARY MICROTOME.

example, with the rocker microtome (fig. 718) every to-and-fro movement of the handle, H, not only cuts a section of the tissue of definite thickness, but also moves the paraffin block forwards in readiness for the next section. And by employing a rectangular block of paraffin of the proper consistency, a long series of sections of the same object, of equal thickness, can be obtained and made to adhere together in a riband (as shown in fig. 718). The sections can be kept in series upon the slide by the employment of some adhesive method of mounting the riband.

For celloidin-embedded preparations it is necessary to cut the sections with a knife kept wetted with spirit. For this purpose a sliding microtome (fig. 720), in which the knife or razor is moved horizontally over the tissue, with the edge obliquely inclined to the direction of movement, is the most useful. The best arrangement for this purpose, especially for large sections of brain, is one in which the celloidin-soaked object is immersed in spirit during the actual process of making the sections. It is all-important for every kind of microtome that the edge of the knife or razor should be in perfect order.

Methods of mounting in xylol balsam or dammar.—Individual paraffin-cut sections or ribands of sections, such as are cut with the rocking and other microtomes, are fixed to a glass slide or cover-glass—as a preliminary to being treated with stains and other fluids—in the following way: The slide (or cover-glass), after having been carefully cleaned, is smeared very thinly with fresh white of egg: this can be done with the finger or with a clean rag; the albuminized slide is then put aside to dry, protected from dust. A dilute solution of agar jelly (1 gm. per 1000 c.c. distilled water) may be used in place of white of egg. It is convenient to prepare a large number of slides at a time in this way, and to keep them at hand in a suitable receptacle. When required for use a little water is poured on to the slide and the riband of sections is placed on the water, which is then warmed on a hot plate or over a small flame until the paraffin becomes flattened out, without actually melting. The water is then drained off, the slide put in a warm place for the remainder of the water to evaporate (this will take from half an hour to an hour according to the size of the section and the temperature at which it is kept), and then heated sufficiently to melt the paraffin. It is next immersed in xylol to remove the paraffin, after which the sections may, if already stained, be mounted at once in dammar; if not stained, they are treated, after xylol, first with absolute and then with gradually lower grades of alcohol, then with water and stained, and finally are passed through water, alcohol (in grades), clove oil, and xylol, into dammar. For many sections some of the grades of alcohol can be omitted, but it is always well to employ 50 per cent. alcohol between water and absolute alcohol.

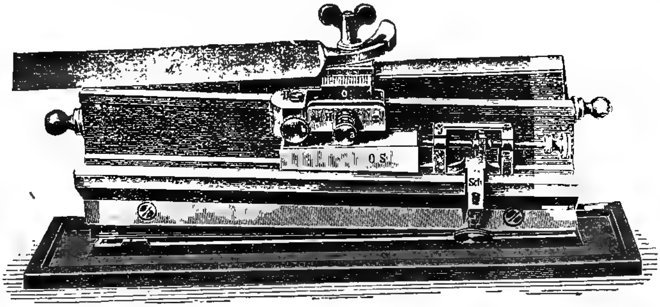

FIG. 720.—INCLINED PLANE MICROTOME.

A simpler method, but one which, in most cases, answers the purpose perfectly well, is to place the riband or the individual sections cut from paraffin on the surface of water in a basin, just sufficiently warm to flatten out the paraffin, but not to melt it, then pass a perfectly clean slide under the surface of the water and float the sections on to it; remove, drain off the water, and put the slide and sections aside for an hour or more until all the water has evaporated. The sections are found to have adhered firmly to the slide (they may, if desired, be yet more firmly fixed by drawing a brush moistened with solution of celloidin in oil of cloves over them). The paraffin can now be removed by washing the slide with xylol or immersing it in xylol. If not previously stained they can then be passed through alcohols and stained and mounted as just described. After certain hardening solutions have been used (bichromates or osmic acid) the sections cannot be fixed by the water method alone: an albuminized slide is necessary.

It is convenient to keep the several solutions which are required for removing the paraffin and for staining, dehydrating, and clearing the sections after they are fixed to the slide, in cylindrical tubes or in grooved glass receptacles in a regular row upon the working table, the slide being transferred from one to the other in succession. Such a series would be (1) xylol; (2) absolute alcohol; (3) 75 per cent. alcohol; (4) 50 per cent. alcohol; (5) distilled water; (6) staining solution; (7) tap water; (8) distilled water; (9) 50 per cent. alcohol; (10) 75 per cent. alcohol; (11) absolute alcohol; (12) xylol. The changes are sometimes effected by pouring the solutions over the sections and draining off.

The following table shows the methods to be adopted for the treatment of paraffin-cut sections or ribands of sections:—

1. Float on to a slide or cover-glass in warm water: the glass may previously have been smeared with egg-white.
2. Drain off water and allow to dry *completely*.
3. Warm until paraffin is just melted.
4. Dissolve paraffin away with xylol.

If tissue is already stained in bulk.

5. Mount in dammar.

For sections cut by the *freezing* or *celloidin methods*, if the tissue has already been stained in bulk, the sections need only be put through Nos. 9 and 10, and then mounted in dammar. If the tissue has not already been stained, begin at No. 6.

If tissue is not already stained.

5. Absolute alcohol.
6. Descending grades of alcohol.
7. Stain.
8. Water.
9. Ascending grades of alcohol.
10. Xylol (this may be preceded by bergamot oil).
11. Mount in dammar.

Methods of staining.—Staining by dyes is dependent partly upon the physical processes of osmosis and absorption, partly upon chemical affinities. The theory of stains has been treated of at great length by various authors:[1] it would occupy far too much space to deal with the matter in this work. The methods of staining employed for teased preparations have been dealt with under the several tissues. We may here, therefore, confine our attention to the staining of sections.

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[1] The literature is given in the books mentioned in the footnote on p. 537.

The fluids most commonly employed for the staining of sections are: (1) Solutions of hæmatoxylin and alum; (2) solutions of carmine with or without alum; (3) certain aniline dyes. The time of immersion in the staining fluid varies according to the strength of the fluid and the mode by which the tissue has been hardened. The necessity of staining sections may in some cases be avoided by staining the tissue in bulk before embedding. For this purpose a small piece of hardened tissue well washed with distilled water is placed for twenty-four hours or more in a moderately diluted solution of hæmalum or of Ehrlich's hæmatoxylin; this may be followed by two or three hours in a 1 per cent. aqueous solution of eosin. The tissue is then passed through alcohol, which removes excess of eosin. It may be cut into sections by either the paraffin or freezing method. If the latter be employed the sections are placed in tap-water to remove gum, are floated on to a slide, and the excess of water allowed to drain off. Alcohol is then dropped on from a drop bottle and the section is pressed flat with blotting or tissue paper. This fixes the section to the slide. It is then dehydrated by absolute alcohol in the usual receptacle, and passed through clove oil or xylol into dammar. If the tissue has not been stained in bulk the sections are usually stained on the slide in the manner described on p. 544. The most useful method for class purposes is to immerse the slide on which the sections are fixed, which has been carried through xylol and alcohol into water, in hæmatoxylin solution for fifteen minutes; after rinsing with water they are counterstained with eosin for five minutes, and are then carried through alcohol and xylol into dammar. Sections may be stained whilst still infiltrated with paraffin by floating them as they are cut on to the surface of a staining solution, which is gently warmed (but not enough to melt the paraffin). Under these circumstances they require far longer exposure to the stain. The subsequent treatment is simple, for they need only be transferred to warm water, floated on to a slide and allowed to dry. The paraffin is then melted and allowed to set; the solidified paraffin is dissolved away with xylol, and the sections are mounted in dammar.

The following are some of the principal staining solutions:—

1. *Delafield's hæmatoxylin.*—To 150 c.c. of a saturated solution of potash alum in water add 4 c.c. of a saturated solution of hæmatoxylin in alcohol. Let the mixture stand eight days, then decant, and add 25 c.c. of glycerine and 25 c.c. of methylic alcohol. The solution must stand a few days before it is ready for use.

To stain free sections add a few drops of this solution to a watch-glassful of *distilled* water. If overstained the excess of colour can be removed by alcohol containing 1 per cent. nitric or hydrochloric acid. With long keeping this hæmatoxylin solution becomes reddened; a trace of ammonia will restore the blue colour.

2. *Ehrlich's hæmatoxylin.*—Dissolve 2 gm. hæmatoxylin (or hæmateïn) in 100 c.c. alcohol; add 100 c.c. water, 100 c.c. glycerine, and 10 c.c. glacial acetic acid: also potash alum to saturation. This solution will keep almost indefinitely: it is valuable for staining in bulk, since it does not easily overstain. For sections the solution may be diluted either with distilled water or with a solution containing one part alcohol to two parts distilled water. After the sections have been stained they must be thoroughly washed with tap-water. This develops the blue colour of the hæmatoxylin.

3. *Kultschitzky's hæmatoxylin.*—Dissolve 1 gm. hæmatoxylin in a little alcohol, and add to it 100 c.c. of a 2 per cent. solution of acetic acid. This solution is valuable for staining sections of the nervous system (see Weigert-Pal process).

4. *Hæmalum.*—Hæmatoxylin-alum solutions acquire their colouring properties only as the hæmatoxylin on keeping becomes converted into hæmateïn. The latter substance may, therefore, as recommended by Mayer, be used advantageously in place of hæmatoxylin if the stain is required immediately. The following is the mode of preparing the solution : Dissolve 50 gm. of ammonia alum in 1 litre of distilled water, and 1 gm. of hæmateïn in 100 c.c. of rectified spirit. Add the hæmateïn solution gradually to the alum. The mixture is ready for staining at once, either as it is or diluted with distilled water. A small piece of thymol or a little carbolic acid should be added to prevent the growth of moulds.

5. *R. Heidenhain's method.*—After hardening in alcohol, or in saturated solution of picric acid and then in alcohol, place the tissue from twelve to fourteen hours in a 0·3 per cent. aqueous solution of hæmatoxylin, and then from twelve to twenty-four hours more in a 0·5 per cent. solution of yellow chromate of potash, which may be changed more than once. Then wash in water, place in alcohol, pass through xylol, and embed in paraffin.

6. *M. Heidenhain's iron-hæmatoxylin method.*—Harden in sublimate, or Zenker, or formol, followed by alcohol ; fix sections to slide by water method ; treat with iodised alcohol if sublimate has been used ; transfer to 2·5 per cent. iron alum (sulphate, or tartrate, of iron and ammonia) and leave a quarter of an hour or longer ; rinse with distilled water ; place in 0·5 to 1 per cent. pure hæmatoxylin in water containing 10 per cent. alcohol, for a few minutes ; wash with water ; differentiate in the iron and ammonia solution until nearly decolorised : the sections must be examined from time to time with a low power after washing away the iron alum with water. When differentiated wash for fifteen minutes in tap-water ; dehydrate and mount in the usual way. This method is especially adapted for exhibiting the centrosomes of cells and the alterations of the nucleus in cell-division. It is also a good general method for many tissues.

Both the process of mordanting with iron alum and the subsequent staining with hæmatoxylin may often with advantage be considerably prolonged (up to twelve hours or more).

7. *Carmalum.*—This is useful either for sections or bulk staining. If the sections are subsequently passed through alcohol containing picric acid in solution a double stain is produced.

Carminic acid	1 gm.
Ammonia alum	10 gm.
Distilled water	200 c.c.

Boil together, allow to cool, and filter. Add 1 c.c. formol or carbolic acid to prevent the growth of moulds.

8. *Carminate of ammonia.*—Prepared by dissolving carmine in ammonia, and allowing the excess of ammonia to escape by slow evaporation. The solution may be diluted with water as required.

9. *Borax-carmine.*—Dissolve 4 gm. borax and 3 gm. carmine in 100 c.c. of water with the aid of heat. Add 100 c.c. of 70 per cent. alcohol, let stand two days or more and filter. This solution improves on keeping. It is used for staining in bulk. After staining (for several days) the tissue is transferred, without washing, to 70 per cent. alcohol containing 5 drops of hydrochloric acid to 100 c.c. in order to fix the colour. It should remain in this for two or three days. Then proceed with dehydration.

10. *Picro-carminate of ammonia.*—This is a double stain. *a. Ranvier's picro-*

carmine.—To a saturated solution of picric acid add a strong solution of carmine in ammonia, until a precipitate begins to form. Evaporate on the water bath (or, better, allow it to evaporate spontaneously) to one half its bulk; add a little carbolic acid to prevent the growth of moulds; filter from the sediment. β. *Bourne's picro-carmine.*—"Add 5 c.c. of ammonia to 2 gm. carmine in a bottle capable of containing about 250 c.c. Stopper, shake, and put aside till next day. Add slowly, shaking the while, 200 c.c. of a saturated solution of picric acid in distilled water. Put aside till next day. Add slowly, constantly stirring, 11 c.c. of 5 per cent. acetic acid. Put aside till next day. Filter; to the filtrate add four drops of ammonia, put back in the stoppered bottle" (Langley).

11. *Picric acid.*—A saturated solution of picric acid in rectified spirit may be used as a second stain after hæmatoxylin or carmine. An excess of picric acid is dissolved out by rinsing with fresh spirit. This form of double stain is valuable for exhibiting keratinised tissues and muscle-fibres.

12. *Van Gieson's stain.*—This is also a double stain. It consists of a saturated solution of picric acid in water, with 5 c.c. of a 1 per cent. aqueous solution of acid fuchsin added to each 100 c.c. It stains connective-tissue fibres bright red; muscle-fibres and epithelium yellow. Sections may first be stained deeply with hæmalum, then placed in Van Gieson's stain for some minutes, then passed through 75 per cent. alcohol, absolute alcohol and clove oil or xylol, and mounted in dammar. The method is suitable for frozen and celloidin sections. It is valuable for the nervous system: for this it is recommended to increase the proportion of the acid-fuchsin solution to fifteen parts per cent.

Aniline dyes.—These are used either in simple aqueous solution, or in 0·01 per cent. solution of caustic potash, or in water shaken up with aniline oil; it is usual to overstain a tissue with them, and subsequently to decolorise with absolute alcohol containing $\frac{1}{5}$ its bulk of aniline oil (from this mixture the sections can pass directly into xylol) or with alcohol containing 0·1 to 1 per cent. hydrochloric acid: this is followed by absolute alcohol and this by xylol. The aniline colours most employed are the "basic" dyes—methylene blue, gentian violet, toluidin blue, thionin, safranin, and vesuvin; and the "acid" dyes—eosin, erythrosin, magenta or acid fuchsin, orange G. and methyl blue; "neutral" dyes are also used.

13. *Eosin.*—A 1 per cent. solution in water. The sections are first stained deeply with hæmatoxylin and rinsed with distilled water. They are then stained with the eosin solution, passed through 75 per cent. alcohol, and then through strong spirit—which is allowed to dissolve out some but not all of the eosin stain—into clove oil: they are finally mounted in dammar. Erythrosin may be used in place of eosin. An alcohol-soluble eosin is employed in certain special methods of staining.

Eosin colours hæmoglobin of an orange-red colour; so that the blood-corpuscles are well shown when a fixing fluid has been employed which does not remove the hæmoglobin from them (such as mercuric chloride, bichromate of potassium, and formol).

14. *Methylene blue and eosin.*—A double stain is obtained by combining eosin with methylene blue or toluidin blue, the sections being first stained for ten minutes in 1 per cent. aqueous eosin and then, after rinsing with water, for twenty minutes in 1 per cent. of the blue solution, after which they are decolorised by absolute alcohol or absolute alcohol and aniline oil. The decolorisation is arrested by xylol.

15. *Jenner's stain.*—This is made by dissolving in pure methyl alcohol the

precipitate which is produced when eosin solution is added to methylene-blue solution. It is valuable for blood films.

16. *Leishman's stain* is largely used for the same purpose. It is made by dissolving 1 part medicinally pure methylene blue in 100 parts 0·5 per cent. sodium bicarbonate solution with the aid of heat and precipitating by five times its bulk of a 0·1 per cent. aqueous solution of yellow water-soluble eosin. The precipitate is collected on a filter, and when dry is dissolved in methylic alcohol in the proportion of 0·1 gm. to 60 c.c. (Wright).

17. *Mann's double stain.*—A good double stain for sections is the methyl blue eosin of G. Mann (see *Methods of Physiological Histology*, p. 216). To prepare this take 35 c.c. of a 1 per cent. solution of methyl blue in distilled water, and 45 c.c. of a 1 per cent. solution of eosin in distilled water: mix and add 100 c.c. of distilled water. In sections it stains connective-tissue fibres and mucus-containing cells deep blue. Diluted ten times it can be used also for fresh tissues. Mann's stain is used in two ways. (*a*) Short method. Sections are simply placed in the solution for a few minutes. (*b*) Long method. This consists in staining the sections (which should be fixed to the slide) overnight, rinsing with distilled water, dehydrating in absolute alcohol and differentiating in absolute alcohol to every 30 c.c. of which 5 drops of a saturated solution of caustic potash in absolute alcohol has been added. When the sections have become reddish wash with absolute alcohol and place in distilled water which may be faintly acidulated with acetic acid.

18. *Fuchsin* or *magenta.*—A 1 per cent. solution in 50 per cent. alcohol (to which 1 drop of 1 per cent. alcohol-solution of gentian or methyl violet may be added per cubic centimeter just before use) is an excellent stain for fresh connective tissue. It colours all the elements of the tissue but most intensely the elastic fibres. Magenta may also be used for staining in bulk, especially for developing bone or tooth and lymph-glands. The piece of tissue (*e.g.* fœtal limb or jaw) is left for several days in a 1 per cent. solution of magenta, then dehydrated in absolute alcohol; placed for a few hours in a small quantity of clove oil, and finally transferred through xylol to molten paraffin.

19. *Acid fuchsin* or *rubin S.* is a derivation of fuchsin; it enters into the composition of Van Gieson's and Mallory's stains. It especially colours the white fibres of connective tissue, but also brings out some of the cell structures, especially the centrosomes and achromatic spindles and the nucleoli.

20. *Mallory's stain for connective tissue.*—The sections are placed for three minutes in acid fuchsin (1 per 1000); then washed in water and immersed for several minutes in phospho-molybdic acid. They are then again thoroughly washed in water, and placed for two minutes or more in the following solution:—

Aniline blue	0·5 g.
Orange G.	2·0 g.
Oxalic acid	2·0 g.
Water -	100 c.c.

After being stained with this they are passed through water, alcohol, and xylol into dammar.

21. *Orcein* is a dye obtained from lichens. It is chiefly useful for staining elastic fibres in sections of organs. For this purpose 1 gm. orcein is dissolved in 100 c.c. absolute alcohol, containing 1 c.c. hydrochloric acid. The sections are placed in some of this solution in a watch-glass for about an hour. They are dehydrated in alcohol, which removes the excess of stain; then passed through xylol into dammar.

22. *Flemming's method for staining dividing nuclei.*—The tissue is fixed in

Flemming's solution (see p. 538), and small shreds or thin sections are placed for two days in saturated alcoholic solution of safranin, mixed with an equal amount of aniline water. They are then washed with distilled water and decolorised in aniline alcohol or in alcohol containing 1 per 1000 hydrochloric acid until the colour is washed out from everything except the nuclei. They are then again rinsed in water, and placed in saturated aqueous solution of gentian violet for two hours, washed again in distilled water, decolorised with aniline alcohol until only the nuclei are left stained, then transferred to bergamot oil or xylol, and from this are mounted in dammar. Gentian violet and several other basic aniline colours may be employed in place of safranin from the first. Delafield's hæmatoxylin (followed by acid) and Ehrlich's hæmatoxylin also stain mitotic figures well. The iron-hæmatoxylin method is also valuable for this purpose, as well as for exhibiting the centrosomes and the changes of the achromatic spindle.

23. *Staining with nitrate of silver* (Recklinghausen).—Wash the fresh tissue with distilled water; immerse in 0·5 to 1 per cent. nitrate of silver solution for from one to five minutes; rinse with distilled water and expose until just brown to bright sunlight. The tissue, if it is a thin membrane, may be mounted in glycerine. But a better plan is to spread it out flat in water on a slide, drain off the water, allow the tissue to dry completely, and finally mount it in dammar. This method is used to exhibit endothelium, and generally to stain intercellular substance. It depends upon the fact that the chlorides of the tissues are almost exclusively confined to the intercellular substance.

Most of the following methods are especially useful in investigations relating to the nervous system:—

24. *Marchi's method.*—This method is of value for staining nerve-fibres in the earlier stages of degeneration, before sclerosis sets in (especially a few days after the establishment of a lesion). The degenerated medullated fibres are stained black, whilst the rest of the section remains almost unstained. In employing the method for the brain or cord the organ is first fixed or partially hardened by immersion for ten days in Müller's fluid (p. 538). Thin pieces of the tissue are then cut and are placed singly in a fairly large quantity of a mixture of Müller's fluid (2 parts) and 1 per cent. osmic acid (1 part). They are left in this for at least a week: if they are large it is necessary to change the fluid once or twice.

The pieces may then be washed in water, passed through grades of alcohol and through xylol or bergamot oil into paraffin, and the sections mounted at once—after removing the paraffin with xylol—in dammar. It is possible to stain sections by Marchi, but the process is complicated and somewhat uncertain.[1]

25. *Weigert-Pal method.*—This method is chiefly used for the central nervous system. By it all medullated nerve-fibres are stained dark, while grey matter and sclerosed tracts of white matter are left uncoloured. The following modification of the original method is recommended: Pieces which have been hardened in Müller's fluid and afterwards kept a short time in alcohol (without washing in water) are embedded in celloidin, and sections are cut as thin as possible. Or sections may be made by the freezing method direct from Müller's fluid, if the pieces of tissue to be cut are first soaked in gum-water for a few hours. In either case the sections are placed in water, and from this are transferred to Marchi's fluid (see above, § 24), in which they are left overnight. They are then again washed in water and transferred to Kulschitzky's hæmatoxylin (see p. 545, § 3). In this they are also left overnight, by which time they will be completely black.

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[1] See Hamilton, *Brain*, 1897, p. 180.

After again washing in water they are ready to be bleached. This is accomplished by Pal's method as follows: Place the overstained sections, first in 0·25 per cent. solution of potassium permanganate for five minutes (or for a longer time in a weaker solution); rinse with water; transfer to the following bleaching solution, viz. sulphite of soda 1 gm., oxalic acid 1 gm., distilled water 200 c.c.[1] The stain is usually sufficiently differentiated in a few minutes; but the sections can be left longer in the bleaching solution without detriment. If after half an hour they are not differentiated enough, they must be put again (after washing) into the permanganate for some minutes, and then again into the bleaching solution. After differentiation they are passed through water, grades of alcohol (with or without eosin), and oil of bergamot (or xylol), to be mounted in dammar. The advantages which this modification has over the original method are (1) even the finest medullated fibres are brought to view with great surety; (2) the staining of the fibres is jet black, and offers a strong contrast to the colourless grey matter; (3) the sections are easily seen and lifted out of the acid hæmatoxylin, which has very little colour; (4) it is difficult to overbleach the sections; (5) the stain is remarkably permanent.

As an improvement on the above, Bolton recommends to harden with formol, place the sections for a few minutes in 1 per cent. osmic acid, stain for two hours in Kulschitzky's hæmatoxylin at 40° C., and then proceed with the bleaching process.

26. *Staining with chloride of gold.*—α. *Cohnheim's method.*—Place the fresh tissue for from thirty to sixty minutes (according to thickness) in a 0·5 per cent. solution of chloride of gold; then wash and transfer to a large quantity of water faintly acidulated with acetic acid. Keep for two or three days in the light in a warm place. This answers very well for the cornea. If it be principally desired to stain the nerve-fibrils within the epithelium, the cornea may be transferred after twenty-four hours (the outlines of the larger nerves should be just apparent to the naked eye) to a mixture of glycerine (1 part) and water (2 parts), and left in this for twenty-four hours more (Klein).

β. *Löwit's method.*—Place small pieces of the fresh tissue in a mixture of 1 part of formic acid to 2 to 4 parts of water for one-half to one minute; then in 1 per cent. chloride of gold solution for ten to fifteen minutes; then back again into the formic acid mixture for twenty-four hours, and into pure formic acid for twenty-four hours more. After removal from the gold, and whilst in the acid, the tissue must be kept in the dark. This method is especially good for motor nerve-endings in skeletal muscle.

γ. *Ranvier's method.*—Immerse in lemon-juice for five to ten minutes, then wash with water and place in 1 per cent. gold-chloride solution for twenty minutes. Then treat either as in Cohnheim's or as in Löwit's method.

27. *Golgi's chromate of silver methods.*—These are chiefly employed for investigating the relations of cells and fibres in the central nervous system. Two methods are mostly used, as follows:—

α. Very small pieces of the tissue, which has been hardened for some weeks in 3 per cent. bichromate of potassium or Müller's fluid, are placed for half an hour in the dark in 0·75 per cent. nitrate of silver solution, and are then transferred for twenty-four hours or more to a fresh quantity of the same solution (to which a trace of formic acid may be added). They may then be placed in 96 per cent. alcohol (half an hour), and sections, which need not be thin, are cut from celloidin with a microtome or with the free hand after embedding (but not soaking) with paraffin. The sections should be placed in dammar on a cover-glass and the dammar allowed to dry in a uniform layer. The glass is inverted over a thin glass ring and fixed to a slide with the surface of the dammar dependent and exposed to air. Golgi stained preparations must not be mounted and covered in the usual way.

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[1] Diluted sulphurous acid solution may be employed to bleach the sections instead of this solution.

β. Instead of being slowly hardened in bichromate, the tissue is placed at once in very small pieces in a mixture of bichromate and osmic acid (3 parts of 3 per cent. bichromate of potassium or of Müller's fluid to 1 of osmic acid). In this it remains from one to eight days, a piece being transferred each day to 0·75 per cent. silver nitrate. The subsequent procedure is the same as described under α. For some organs it is found advantageous to repeat the process, replacing them for a day or two in the osmic-bichromate mixture after silver nitrate and then putting them back into silver nitrate (Cajal's double method). This method is not only more rapid than that in which bichromate of potassium alone is used, but is more sure in its results. A modification which is recommended by Kopsch is the substitution for the osmium-bichromate mixture of a mixture of 1 part formol and 4 parts bichromate of potassium solution (3·5 per cent.). After three days the pieces are transferred to pure 3·5 per cent. bichromate solution; they are left in this for from one to six days and thence removed to the silver solution.

A combination of the methods under α and β is often found advantageous. To employ this a number of very small pieces of the tissue are placed in 3 per cent. bichromate of potassium as in the slow method. Of these one is every day transferred to osmium-bichromate solution and allowed to remain in this for a few days, after which the silver treatment follows as before.

28. *Cox's chromate of mercury method.*—This serves the same purpose as the Golgi methods but is not so good for fine details. Mix 20 c.c. of 5 per cent. corrosive sublimate solution with 30-40 c.c. distilled water, and add slowly 16 c.c. of 5 per cent. chromate of potassium solution, then further add 20 c.c. of 5 per cent. bichromate of potassium solution to the mixture. Larger pieces of tissue may be taken than for the Golgi methods; they are left for two months or more. Sections are cut by the freezing method and passed through water and successive grades of alcohol, and then through clove oil into dammar. They may be mounted with a cover-glass in the usual way, and as the cells remain white they show up well by reflected light and quite thick opaque sections can be examined. If it is desired to convert the white impregnation into a black one, this can be done by passing the sections through dilute ammonia, but after this they must be mounted like the Golgi preparations without being sealed up.

29. *Intra vitam staining methods.*—(*a*) *Methylene-blue method.*—This method is one of great value for exhibiting nerve-terminations, and in some cases the relations of nerve cells and fibres in the central nervous system. For its application the tissue must be living: it is therefore best applied (Ehrlich) by injecting a solution of methylene blue (1 part to 100 of warm Ringer) into a vein in an anæsthetised mammal, until the whole blood is of a bluish colour; or the injection may be made through the vessels of the part to be investigated, immediately after killing an animal. Fairly good results can also be obtained by immersing small pieces of freshly excised living tissue in a less concentrated solution (0·1 per cent.), or, in the case of the central nervous system, by dusting the methylene-blue powder over a freshly cut surface, allowing some time for it to penetrate and then treating it with picrate of ammonia and Bethe's solution (see below). In either case the tissue should be freely exposed to air; the blue colour then appears in the nerve-cells and axis-cylinders, even to their finest ramifications.

It does not, however, remain, but after a time fades from them, and other tissues then become coloured. To fix the stain the tissue is taken at the moment that the nerve-fibres are most distinctly seen and is placed for an hour or two in saturated solution of picrate of ammonia, after which the preparation can be mounted in glycerine containing picrate of ammonia. But to allow of sections being made from it for mounting in balsam or dammar, it must, subsequently to the treatment with picrate of ammonia, be placed for some hours in Bethe's fluid, viz. :—

Molybdate of ammonia	1 gm.
Chromic acid 2 per cent. solution	10 c.c.
Distilled water	10 c.c.
Hydrochloric acid	1 drop.

This renders the colour insoluble in alcohol.

β. *Dogiel's modification of the methylene blue method.*—The fresh tissue is placed in a capsule containing 1 per 1000 methylene blue and kept at 36° C. for two hours. It is then placed in 6 per cent. molybdate of ammonia for twenty-four hours; washed during four hours in distilled water; dehydrated with alcohol, and passed through xylol into dammar.

γ. *Neutral red.*—This is really a basic dye of a neutral tint, readily converted by alkalies to yellow and by acids to red. It is a relatively non-poisonous substance and can be used for *intra vitam* injection as a concentrated solution in normal saline. It has no specific affinity for neurofibrils but it colours certain cell-granules intensely. It has been used by Bensley for exhibiting by its selective stain the islets of Langerhans of the pancreas.

δ. *Janus green.*—This is a basic aniline dye, readily soluble in water. It can be employed in very dilute solution (1 to 300,000 normal saline) for injection into the blood-vessels. It has been used by Ehrlich for staining nerves intravitally, and by Michaelis for the granules of gland-cells. Bensley has also employed it for showing the islets of Langerhans.

ε. *Bismarck-brown* or *vesuvin* has also been recommended for *intra vitam* injection. It is used in a 0·3 per cent. solution; the tissues are subsequently fixed with 0·2 per cent. chromic acid or 1 per cent. osmic acid. According to Galeotti, Bismarck-brown can be used for vital nerve-coloration in place of methylene blue. It is only slightly poisonous.

30. *Nissl's method of staining the chromatic granules of nerve-cells.*—This is a method of overstaining with methylene blue and subsequent differentiation with alcohol (see § 14). Nissl recommended 90 per cent. alcohol as the hardening agent, but both formol and corrosive sublimate followed by alcohol may be equally well employed. Toluidin blue (Mann) may be used in place of methylene blue. The sections can first be stained with 1 per cent. aqueous solution of eosin, and then, after rinsing in water, with 1 per cent. methylene-blue solution: they are differentiated in aniline alcohol. The effect of heating the solutions to about 70° C. is to accelerate and accentuate the staining.

A Nissl stain may also be obtained by placing thin pieces of the fixed and hardened nervous tissue in 1 per cent. solution of thionin for several days; after which the tissue is dehydrated and embedded in paraffin.

31. *Cajal's methods for exhibiting neurofibrils.*—α. A small piece of the tissue (brain, spinal cord, ganglion, etc.), not more than 4 mm. thick, and preferably from a young or fœtal animal, is placed in 50 c.c. of rectified spirit. After four to six hours in this, followed by twenty-four hours in absolute alcohol, rinse with distilled water and place in a large quantity of 1·5 per cent. solution of silver

nitrate, which is maintained at a temperature of about 35° C. After being five or six days in this solution, the piece is removed, rinsed for a few seconds in distilled water, and transferred for twenty-four hours to the following solution :—

Hydrokinone (or pyrogallic acid)	1 to 1·5 gm.
Distilled water	100 c.c.
Formol	5 to 10 c.c.
Rectified spirit	10 to 15 c.c.

The addition of rectified spirit to the above is not indispensable, but favours penetration. The piece is then washed in water for some minutes, transferred to alcohol, embedded in celloidin or paraffin, and sections are prepared and mounted in the ordinary way.

β. Place several small pieces of the fresh tissue direct in 2 per cent. silver nitrate solution at 35° C. in the dark : a piece is taken out on the third and on each subsequent day until the eighth. The piece is rinsed in distilled water for a minute or two and then immersed in the above developing solution for twenty-four hours : after which proceed as before. The tissue should be placed on cotton wool in the silver solution. The central parts of the tissue are usually best, the superficial parts being often too dark.

32. *Bielchowsky's method for neurofibrils.*—Place small pieces of tissue in 12 per cent. formol for twenty-four hours ; wash for several hours in distilled water ; cut sections by freezing method. Proceed as follows : Place the sections in 2 per cent. nitrate of silver for twenty-four hours; wash in distilled water for a few minutes. Then transfer them to the following solution, viz. : 2 per cent. nitrate of silver 20 c.c., to which three drops of a 40 per cent. solution of caustic potash are added, and enough ammonia to cause the disappearance of the brown precipitate produced. The sections may be left in this solution for some time. They are then passed through distilled water and transferred to 20 per cent. formol solution in tap water. After twenty-four hours in this the sections can be washed with water, dehydrated and mounted in dammar, but it is preferable first to tone them with chloride of gold. This is done by placing the washed sections in very dilute (0·03 per cent.) gold chloride solution acidified with acetic acid. They must then be fixed with acid sodium hyposulphite solution, washed with water, and passed through alcohol and xylol into dammar.

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